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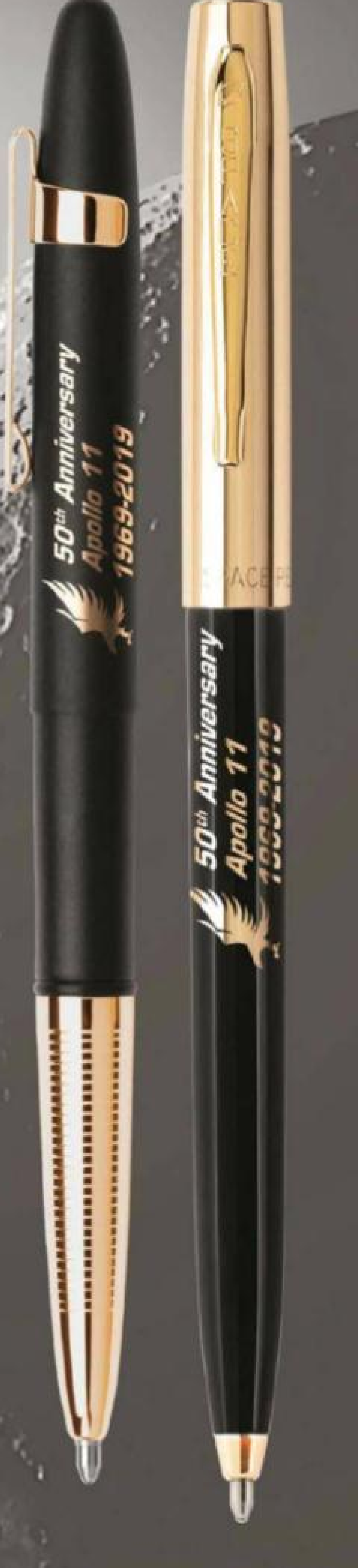

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If you could hear the stars, what would they sound like?

Welcome

We're just one issue away from one of the greatest moments in the history of spaceflight, when it'll be 50 years since humanity first touched down on the surface of the Moon with Apollo 11. We geared up to it last issue, offering you a free eBook on the History of NASA, and this month is of no exception; we hope you enjoy your mini-magazine of some of the rarest images in the Apollo Moon landing photo archives.

This issue, our topics of interest begin at the heart of our true understanding of the universe: the theory of everything. As it sounds, it encompasses every law that governs the cosmos – from quantum gravity and the curvature of space to electricity and magnetism. However, as you'll find this month, not everyone is fully sold on whether such a framework exists – what if our current theories simply can't be linked, as astrophysicists are hoping? Turn to page 16 for our full report.

Also this month, we've got up close and inside China's brand-new super rocket: the Long March. Discover how it works and how it'll get humans to the Moon and even Mars in the future. Speaking of spaceflight, we also caught up with Draper Laboratory's principal director Seamus Tuohy about brand-new efforts to land autonomously on the rugged lunar surface.

Don't forget, head over to page 94 for your **All About Space Annual 2019**, free for all of our readers.

Gemma Lavender
Editor-in-Chief

Our contributors include...

Kelly Oakes
Space science writer
Is there really a theory of everything? Kelly speaks to the cosmologists who are for it, while others are against a unified theory of the cosmos. Details on page 16.

Ryan Weed
Physicist & pilot
The antimatter physicist joins Brian Cox, Sara Seager and more to answer your pressing questions about the universe, planets, rockets and more.

Stuart Atkinson
Astronomer
Take Stuart's tours of the summer night sky this month – there are plenty of clusters, galaxies and nebulae on display in the constellations of Scorpius and Sagittarius.

Lee Cavendish
Staff Writer
We're likely to have uncovered a brand-new exomoon for the very first time – but what do we really know about it? Head over to page 42 for Lee's full report.

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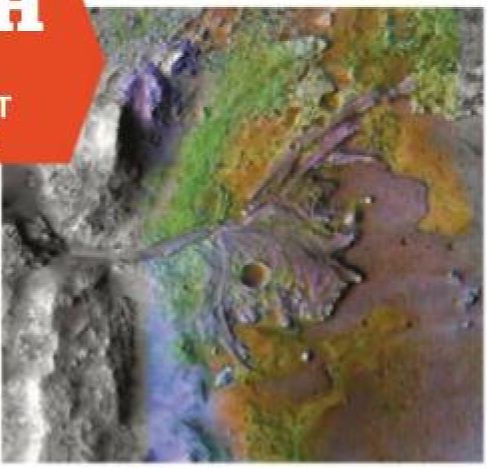

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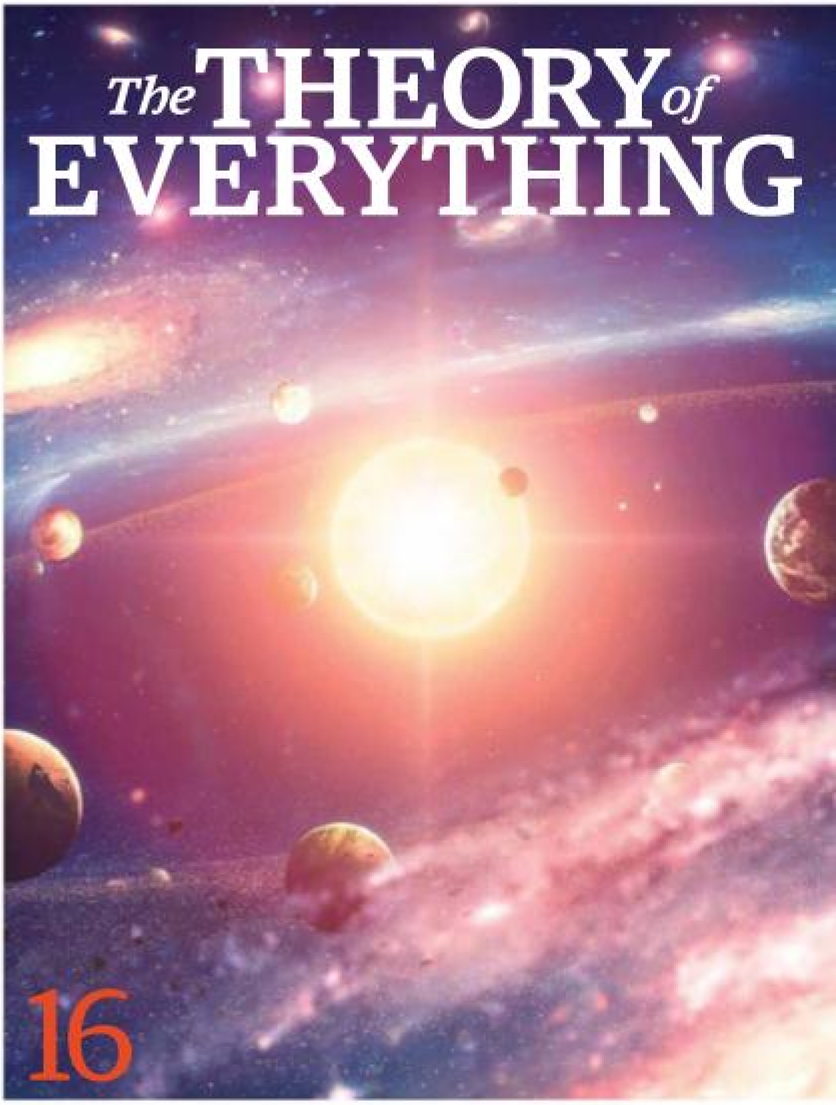

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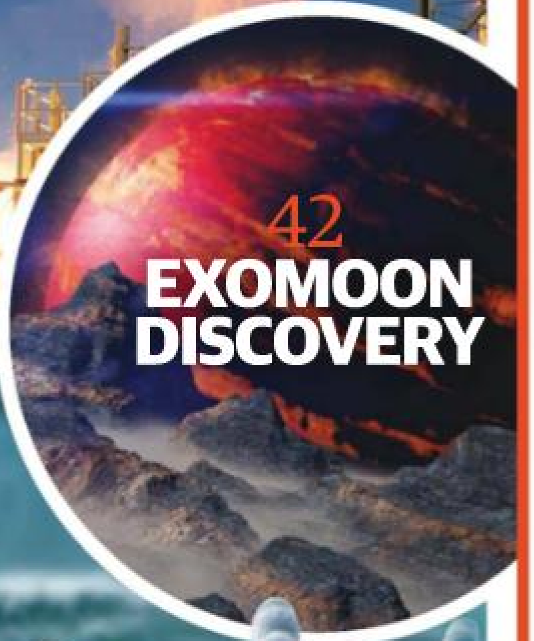

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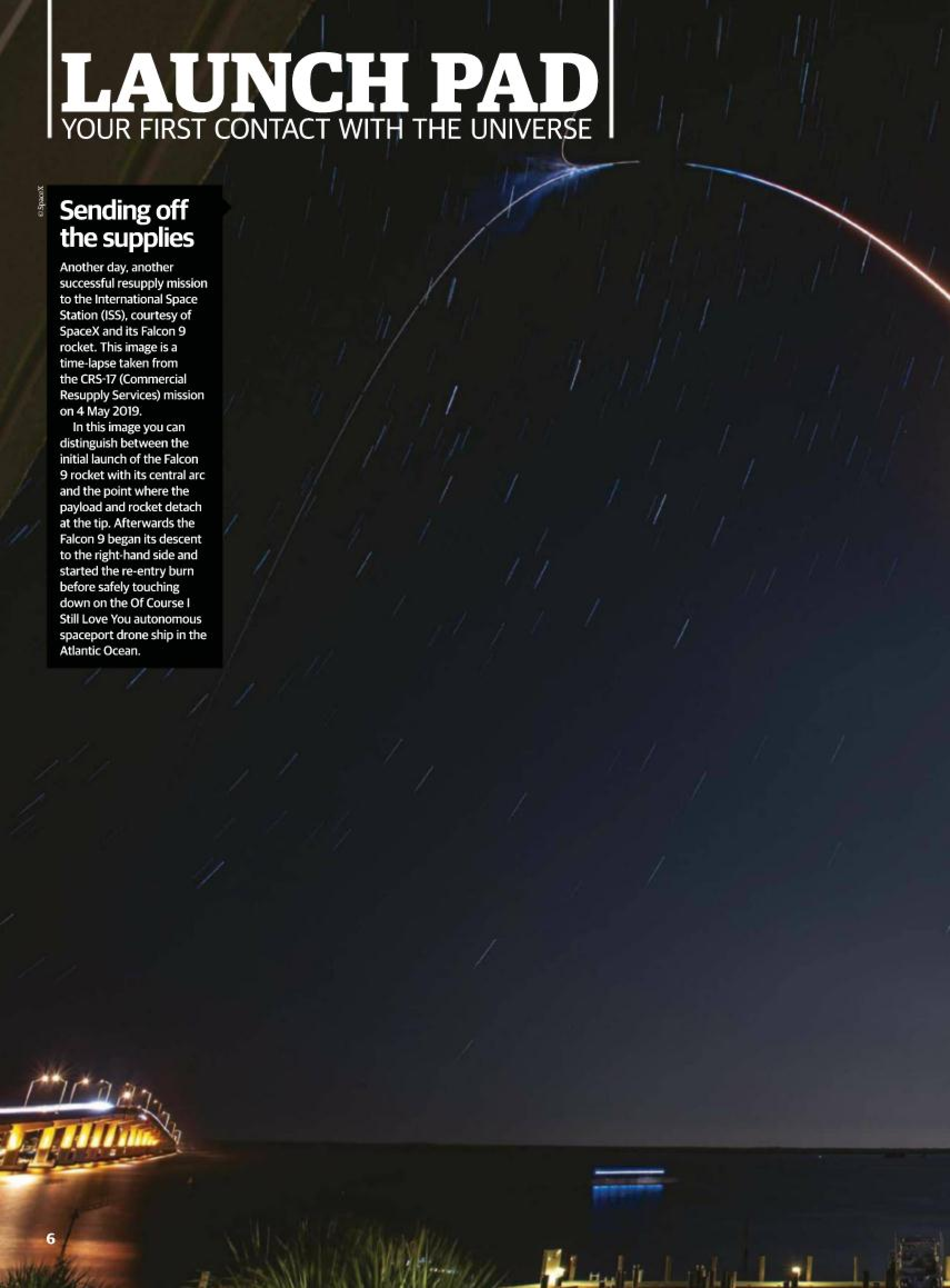

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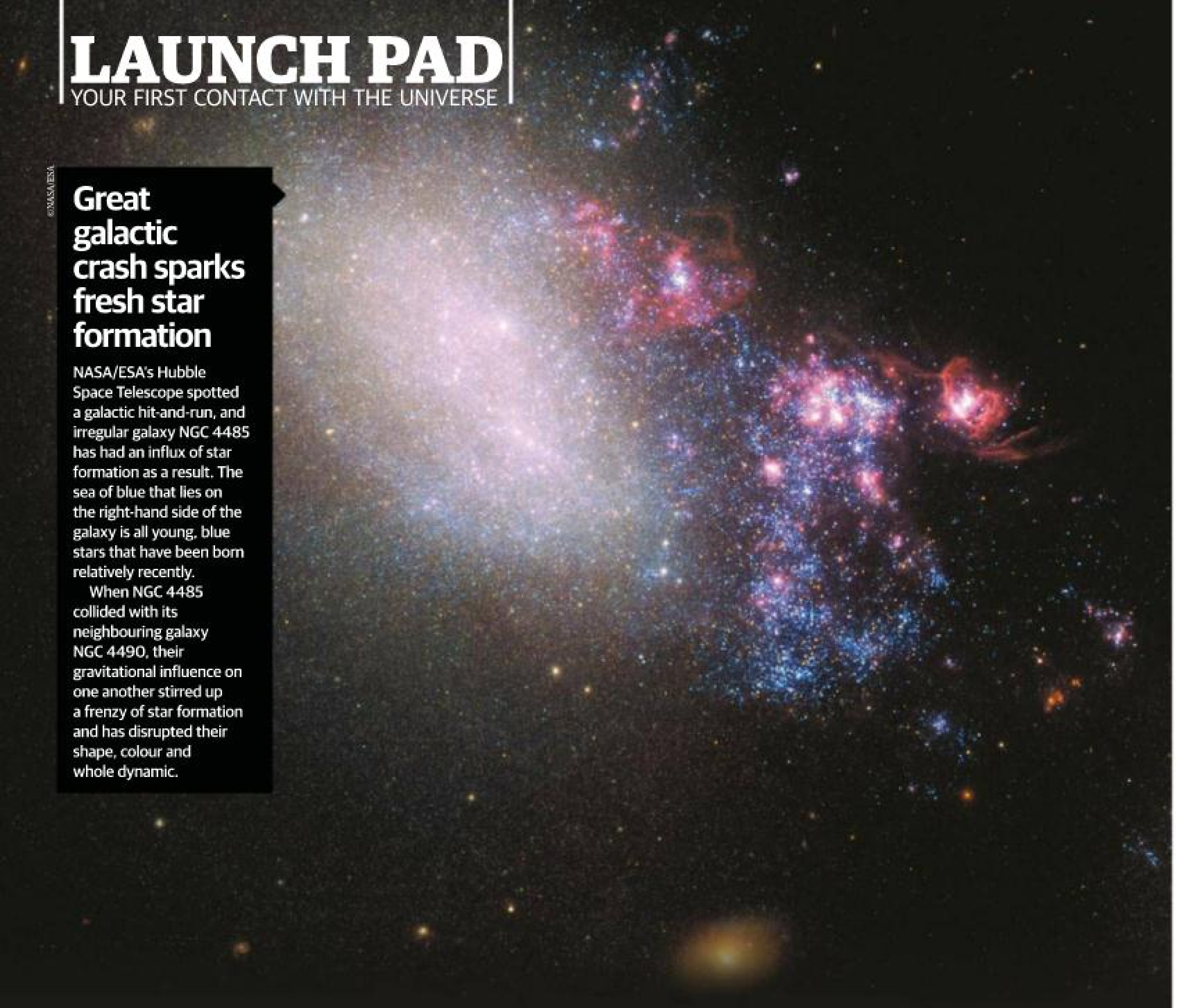
Sending off the supplies

Another day, another successful resupply mission to the International Space Station (ISS), courtesy of SpaceX and its Falcon 9 rocket. This image is a time-lapse taken from the CRS-17 (Commercial Resupply Services) mission on 4 May 2019.

In this image you can distinguish between the initial launch of the Falcon 9 rocket with its central arc and the point where the payload and rocket detach at the tip. Afterwards the Falcon 9 began its descent to the right-hand side and started the re-entry burn before safely touching down on the Of Course I Still Love You autonomous spaceport drone ship in the Atlantic Ocean.



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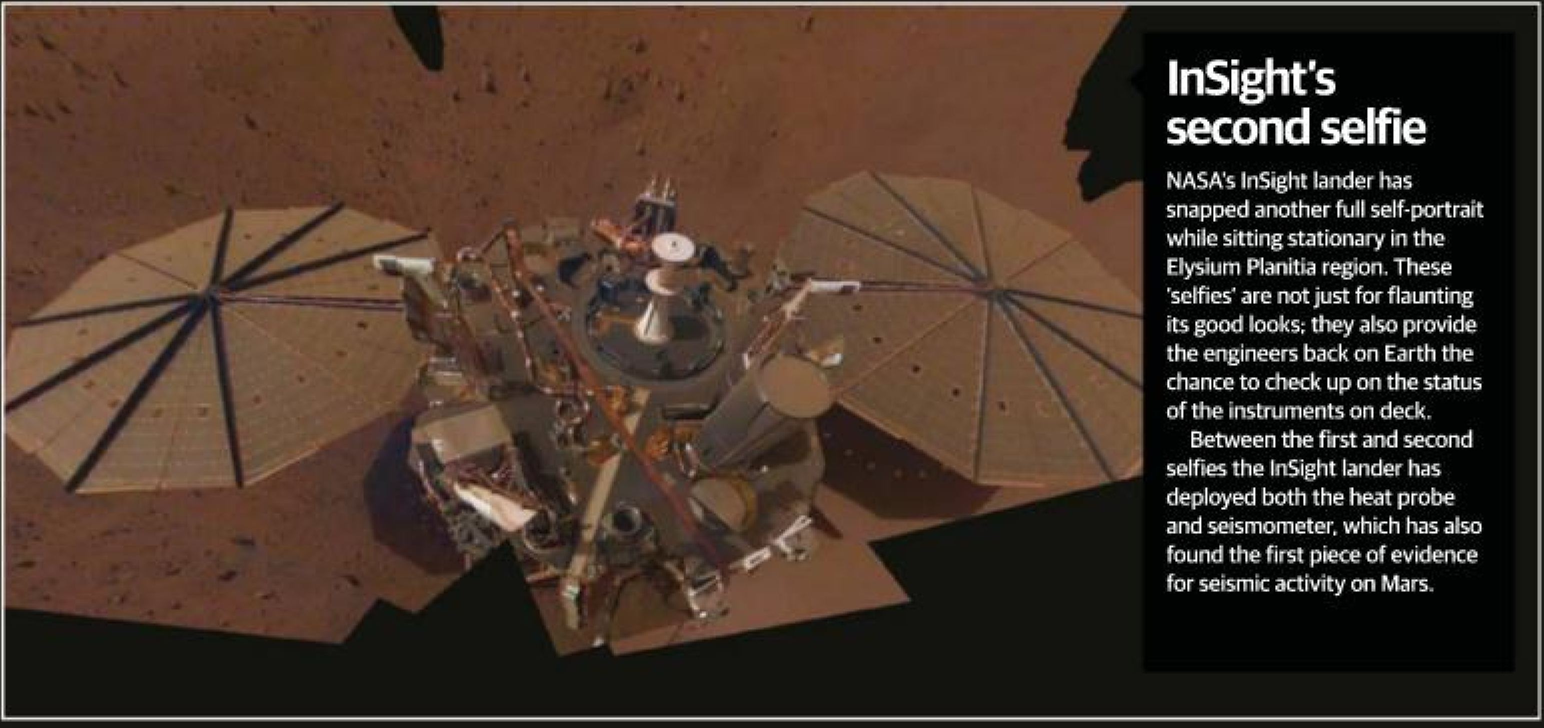
Great galactic crash sparks fresh star formation

NASA/ESA's Hubble Space Telescope spotted a galactic hit-and-run, and irregular galaxy NGC 4485 has had an influx of star formation as a result. The sea of blue that lies on the right-hand side of the galaxy is all young, blue stars that have been born relatively recently.

When NGC 4485 collided with its neighbouring galaxy NGC 4490, their gravitational influence on one another stirred up a frenzy of star formation and has disrupted their shape, colour and whole dynamic.



InSight's second selfie

NASA's InSight lander has snapped another full self-portrait while sitting stationary in the Elysium Planitia region. These 'selfies' are not just for flaunting its good looks; they also provide the engineers back on Earth the chance to check up on the status of the instruments on deck.

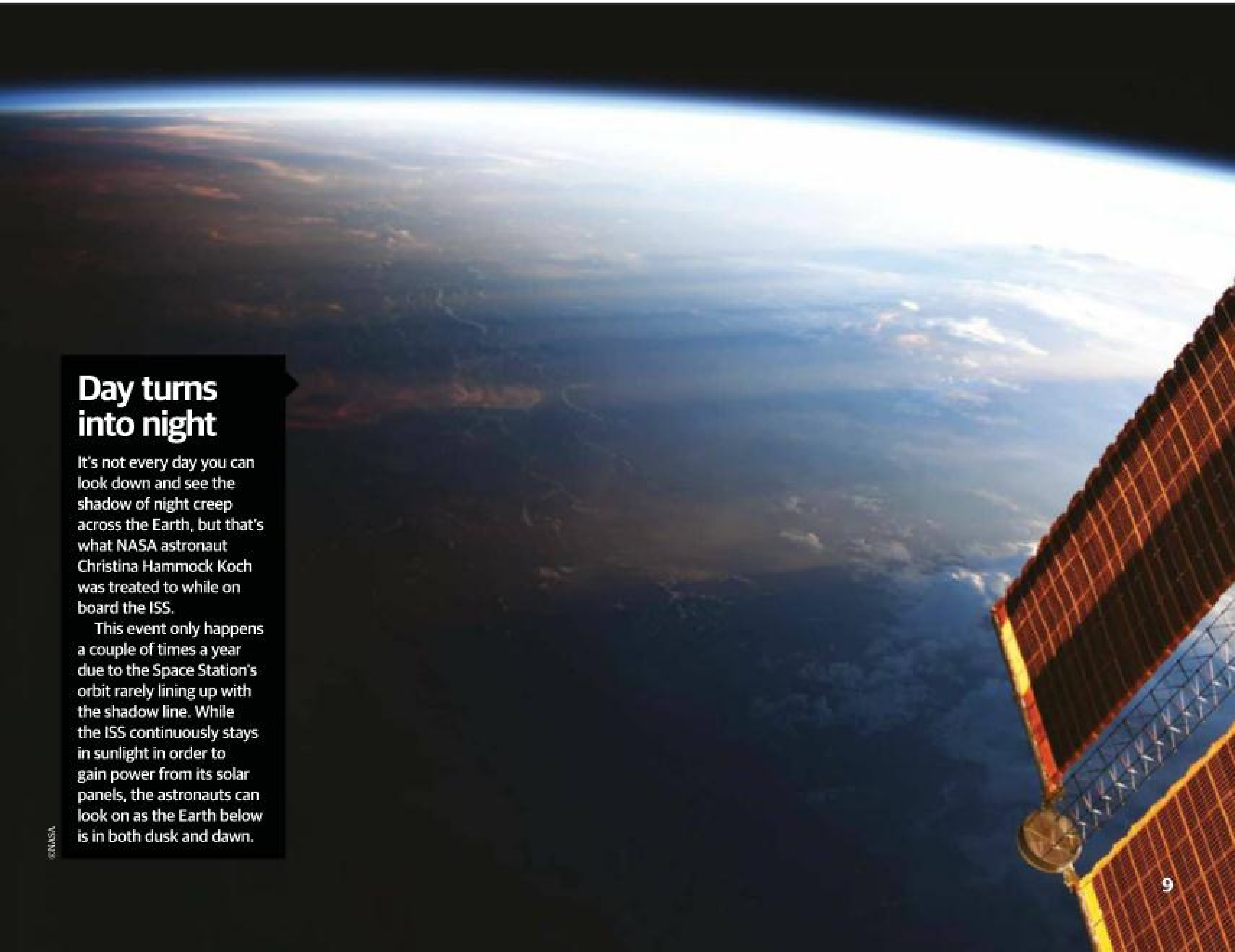
Between the first and second selfies the InSight lander has deployed both the heat probe and seismometer, which has also found the first piece of evidence for seismic activity on Mars.

©NASA/JPL-Caltech

©Blue Origin

New Shepard blasts off to record height

Blue Origin's New Shepard spacecraft will blast customers into space in order to experience the world of weightlessness. 2 May 2019 saw a major step forward for the Blue Origin team as they conducted the 11th test of the impressive reusable rocket-capsule duo and fired it to a personal-record maximum altitude of 106 kilometres (65.8 miles).



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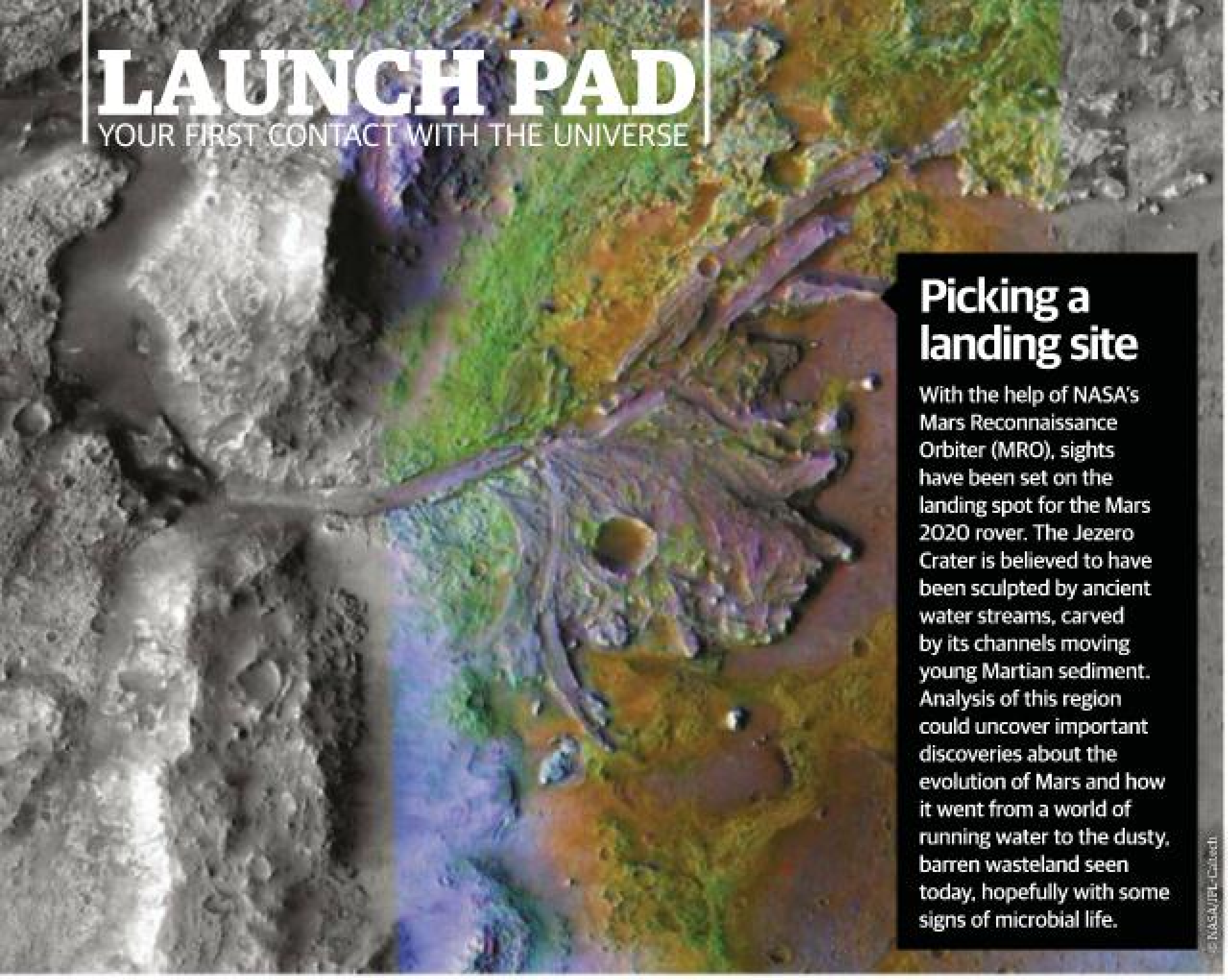
Day turns into night

It's not every day you can look down and see the shadow of night creep across the Earth, but that's what NASA astronaut Christina Hammock Koch was treated to while on board the ISS.

This event only happens a couple of times a year due to the Space Station's orbit rarely lining up with the shadow line. While the ISS continuously stays in sunlight in order to gain power from its solar panels, the astronauts can look on as the Earth below is in both dusk and dawn.



Picking a landing site

With the help of NASA's Mars Reconnaissance Orbiter (MRO), sights have been set on the landing spot for the Mars 2020 rover. The Jezero Crater is believed to have been sculpted by ancient water streams, carved by its channels moving young Martian sediment. Analysis of this region could uncover important discoveries about the evolution of Mars and how it went from a world of running water to the dusty, barren wasteland seen today, hopefully with some signs of microbial life.

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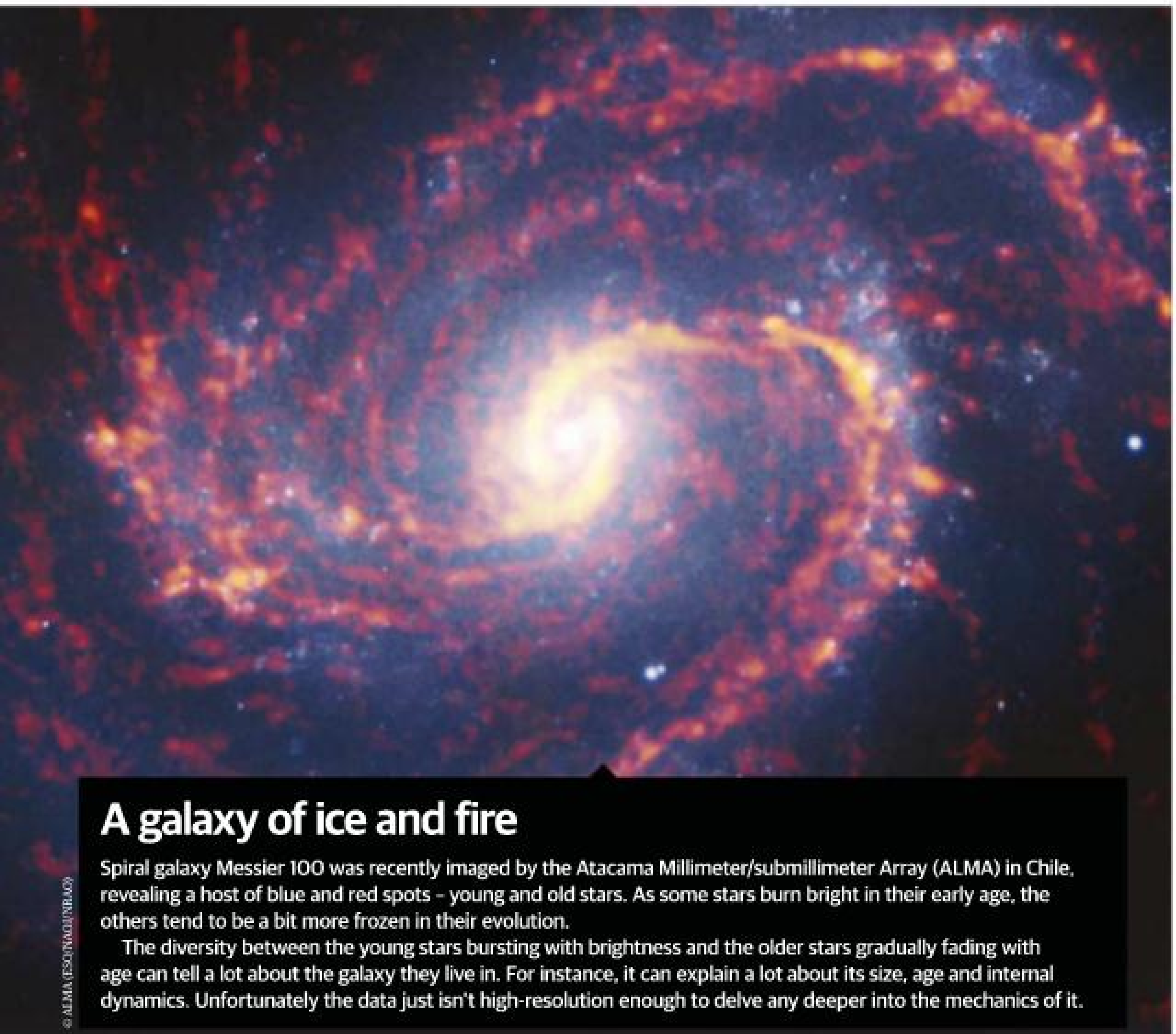

A galaxy of ice and fire

Spiral galaxy Messier 100 was recently imaged by the Atacama Millimeter/submillimeter Array (ALMA) in Chile, revealing a host of blue and red spots – young and old stars. As some stars burn bright in their early age, the others tend to be a bit more frozen in their evolution.

The diversity between the young stars bursting with brightness and the older stars gradually fading with age can tell a lot about the galaxy they live in. For instance, it can explain a lot about its size, age and internal dynamics. Unfortunately the data just isn't high-resolution enough to delve any deeper into the mechanics of it.

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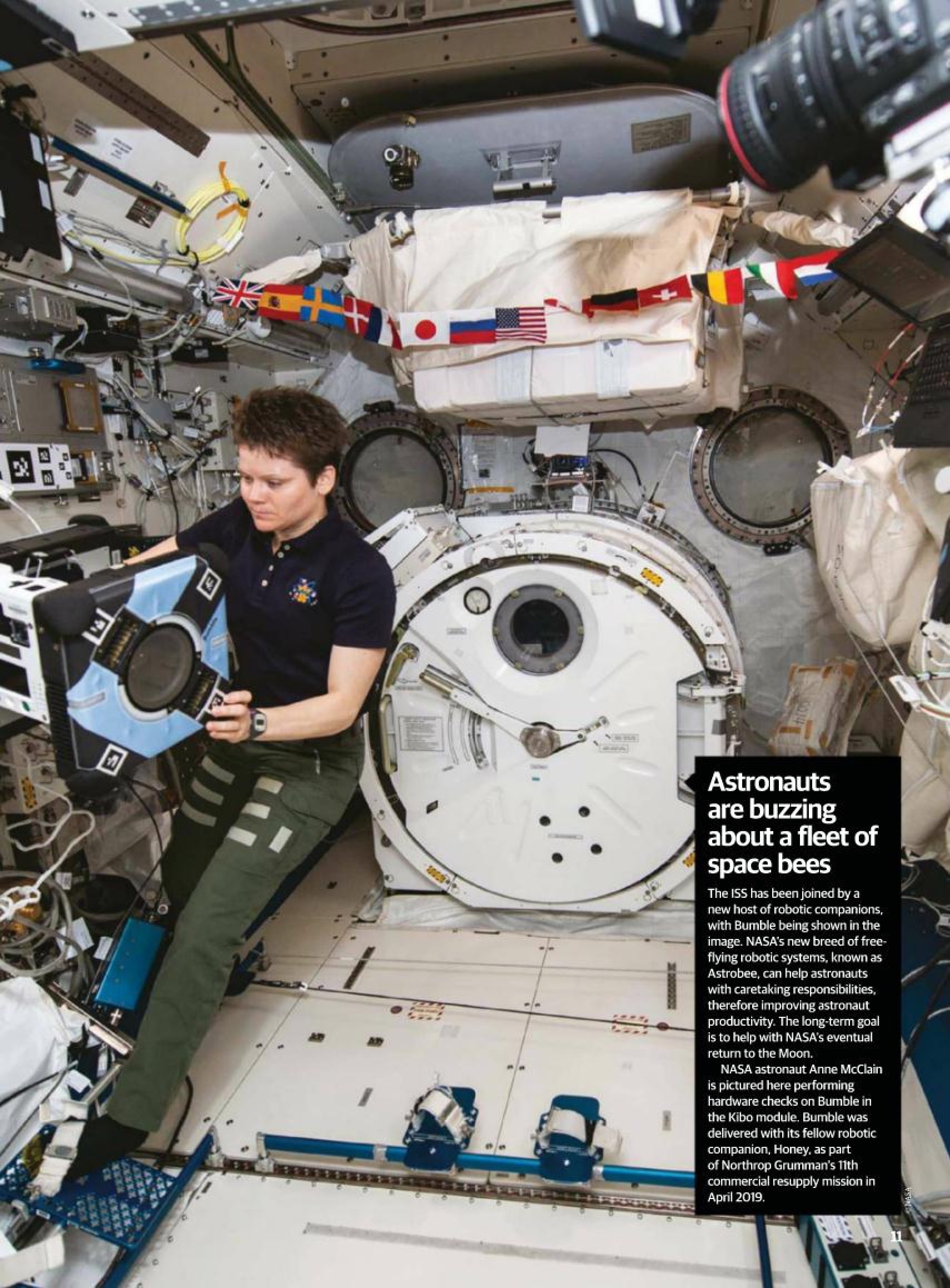

Astronauts are buzzing about a fleet of space bees

The ISS has been joined by a new host of robotic companions, with Bumble being shown in the image. NASA's new breed of free-flying robotic systems, known as Astrobee, can help astronauts with caretaking responsibilities, therefore improving astronaut productivity. The long-term goal is to help with NASA's eventual return to the Moon.

NASA astronaut Anne McClain is pictured here performing hardware checks on Bumble in the Kibo module. Bumble was delivered with its fellow robotic companion, Honey, as part of Northrop Grumman's 11th commercial resupply mission in April 2019.

©NASA

SpaceX's 60-satellite launch marks beginning for Starlink 'internet' project

Words by **Mike Wall**

On 23 May, SpaceX lofted the first five-dozen members of its Starlink broadband constellation to low-Earth orbit (LEO) using one of the company's Falcon 9 rockets. Starlink is designed to provide internet connectivity to people around the world, and it will do so using a truly enormous number of satellites.

Starlink won't be able to provide 'minor' coverage until about 400 spacecraft are up and running, and 'moderate' coverage requires about 800 operational satellites, SpaceX founder and CEO Elon Musk has said. But it doesn't plan to stop at 'moderate'.

"In a year and a half, maybe two years if things go well, SpaceX will probably have more satellites in orbit than all other satellites combined – a majority of the satellites in orbit will be SpaceX," Musk said last week during a prelaunch teleconference with reporters. That milestone will come around Starlink launch number 30, with 1,800 satellites delivered to orbit, he said.

But the number could rise higher still – much higher, in fact. The Federal Communications Commission has granted SpaceX permission to launch a total of nearly 12,000 Starlink satellites.

Musk said SpaceX has taken great pains to ensure the constellation doesn't pose a collision risk to the other denizens of LEO. For example, he claimed the Starlink satellites can automatically navigate around other spacecraft and larger pieces of orbital debris using tracking data provided by the North American Aerospace Defense Command (NORAD).

And this first batch is headed for an operational altitude of 550 kilometres (340 miles) – low enough that they'll get pulled down to Earth by atmospheric drag in a few years even if SpaceX doesn't manage to deorbit them intentionally. "I think we've got a real solution for making sure that we do not create orbital debris," he said. "And, worst-case scenario – the good news there is, the atmosphere cleans it up."

SpaceX isn't the only company with eyes on a LEO broadband constellation. OneWeb, Telesat and Amazon have similar goals, though their networks may not be as big as Starlink.

Starlink is a key part of Musk's long-term plan to help humanity colonise Mars. SpaceX hopes to use Starlink revenue to fund the development of Starship and Super Heavy, the spaceship and rocket the company is building to carry people to the Red Planet and beyond.

Last night's launch featured a Falcon 9 whose first stage had already flown twice. It launched from Cape Canaveral Air Force Base in Florida, with the booster acing its third-ever landing and touching down on SpaceX's drone ship 'Of Course I Still Love You' off the Florida coast.

SpaceX used its own Falcon 9 rocket to launch the satellites

Moderate global coverage will require 800 satellites

© SpaceX

Jupiter's southern hemisphere, as photographed by NASA's Juno spacecraft

© NASA/JPL-Caltech

Hidden winds on Jupiter may be messing with its magnetic field

Words by **Rafi Letzter**

Jupiter's magnetic field has changed since the 1970s, and physicists have proved it. In a paper published 20 May in the journal *Nature Astronomy*, a team of researchers looked at magnetic field data from four past missions to Jupiter – Pioneer 10, which reached Jupiter in 1973; Pioneer 11, which reached Jupiter in 1974; Voyager 1, which reached Jupiter in 1979 and Ulysses, which reached Jupiter in 1992.

They compared that data to a map of the planet's magnetic field produced by the spacecraft Juno, which conducted the most recent and most thorough probe of the giant planet. In 2016 Juno orbited very close to Jupiter, passing from pole to pole, gathering detailed gravitational and magnetic field data. That allowed researchers to develop a thorough model of the planet's magnetic field and some detailed theories as to how it's produced.

The researchers behind this paper showed that data from those four older probes, though more limited as each of them just swung by the planet once, didn't quite fit with the 2016 model of Jupiter's magnetic field.

"Finding something as minute as these changes in something so immense as Jupiter's magnetic field was a challenge," Kimee Moore, a Juno scientist at Harvard and lead author on the paper, said in a statement. "Having a baseline of close-up observations over four-decades long provided us with just enough data to confirm that Jupiter's magnetic field does indeed change over time."

The question raised was what caused the changes to happen? What's going on in Jupiter's dynamo?

The researchers looked at several different causes of magnetic field changes. Their data most closely matched the predictions of a model in which winds in the planet's interior change the magnetic field.

"These winds extend from the planet's surface to over 3,000 kilometres (1,860 miles) deep, where the planet's interior begins changing from gas to highly conductive liquid metal," the statement said.

In truth, researchers can't see that deep into Jupiter, so the depth measurements are really best estimates with several uncertainties, the researchers wrote in the paper. Still, scientists have robust theories to explain how the winds behave.

"They are believed to shear the magnetic fields, stretching them and carrying them around the planet," the statement said.

A star in the Big Dipper is an alien invader

Words by **Mindy Weisberger**

A star in the Big Dipper is an intergalactic alien, according to clues in its chemical fingerprints. The star's chemistry is unlike that of all known stars in the Milky Way, and instead has more in common with stars in nearby dwarf galaxies.

Researchers suspected that the stellar oddball, named J1124+4535, originated in a dwarf galaxy that collided with the Milky Way long ago. According to that theory, when the dwarf galaxy fell apart it stranded this star in our cosmic neighbourhood.

The star was first discovered in the constellation Ursa Major in 2015 by the Large Sky Area Multi-Object Fibre Spectroscopic Telescope (LAMOST) in China. Higher-resolution images were captured in 2017 by the Subaru Telescope in Japan. Spectrum readings from the star revealed that it was low in metals such as magnesium but had unexpectedly high levels of the heavy element europium, an element ratio that was unique in comparison to other Milky Way stars. Analysis of J1124+4535 provides "the clearest chemical signature" of the ancient galaxy mergers that shaped the Milky Way long ago.

The star has a different composition to its neighbours

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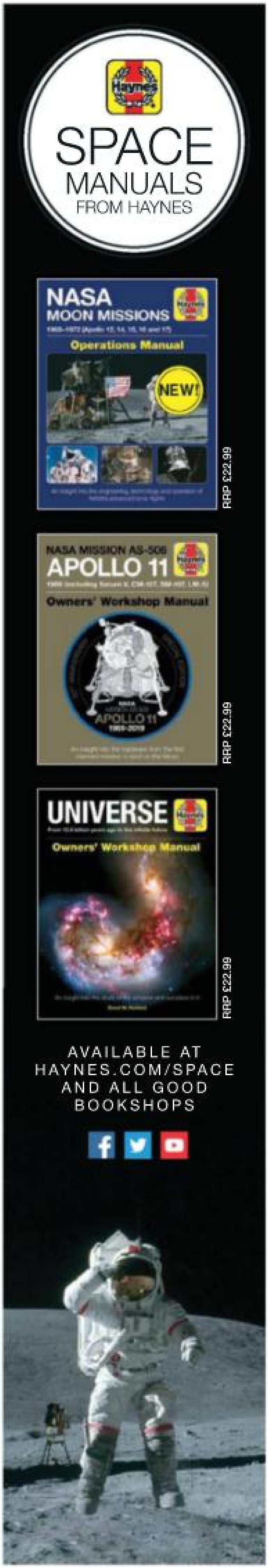

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Haumea is of a similar size to dwarf planet Pluto

New details of dwarf planet Haumea's elusive ring revealed

Words by **Hanneke Weitering**

The oval-shaped dwarf planet Haumea, which is surrounded by an almost perfectly circular ring of particles, is the most distant ringed object in the Solar System. Haumea's ring is too faint to be seen from planet Earth, so astronomers have turned to context clues to find out more about these particles.

In a new study, researchers with the São Paulo Research Foundation in Brazil have detailed the ring's size, shape and other characteristics by simulating the Haumea system on a computer. By simulating the ring's particles in different configurations around the dwarf planet and calculating which scenario would render the ring most stable, the scientists were able to infer the likely qualities of the ring without ever looking at it directly.

"Our study isn't observational. We did not directly observe the ring. No one ever has," Othon Cabo Winter, a professor at São Paulo State University in Guaratinguetá, Brazil, who led the study, said in a statement.

Although astronomers have pretty solid evidence that Haumea has a ring, no one has actually observed the ring directly. Everything we know about Haumea's ring system came from an even more distant object – a bright star named URAT1 533-182543.

In 2017, Haumea briefly passed in front of the star in what's known as a stellar occultation. By looking at how the starlight flickered, astronomers hoped to learn more about Haumea's physical properties, such as its size, shape and density. But to the researchers' surprise, they discovered the ring system, too.

> "Although astronomers have pretty solid evidence, no one has observed the ring directly"

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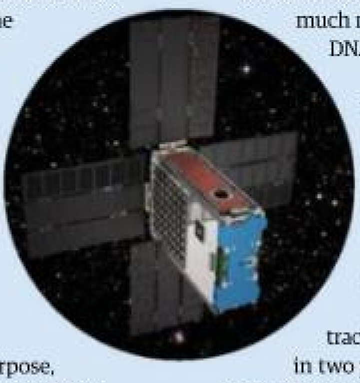
In 2020, NASA will send living things to deep space for the first time since Apollo

Words by **Mike Wall**

NASA is getting ready to launch living creatures to deep space for the first time in nearly five decades. Agency engineers are putting together a briefcase-sized spacecraft called BioSentinel which will carry yeast cells into orbit around the Sun to help scientists better understand the radiation environment beyond our planet's protective magnetic bubble.

BioSentinel is one of 13 cubesats flying aboard the Artemis 1 mission, which is currently targeted for mid-2020. That's 47.5 years after NASA last launched organisms beyond low-Earth orbit – the Apollo 17 astronauts, who reached the moon in December 1972, were the last – the last organisms launched on purpose, anyway; a few hardy microbes stow away on every robotic planetary mission.

"This is new territory," Kimberly Ennico Smith, an astrophysicist at NASA's Ames Research Center, said during a tour of the Silicon Valley facility this past March.



The 14-kilogram satellite will carry two different varieties of the yeast Saccharomyces cerevisiae: the normal 'wild type', which is quite radiation resistant, and a mutant type which is much more sensitive because it can't repair its DNA nearly as well.

BioSentinel team members will monitor the growth and activity of both varieties during the cubesat's time in deep space. They'll do the same with identical yeast payloads transported to the International Space Station, a microgravity environment with much lower radiation levels.

Scientists will also track Saccharomyces cerevisiae growth in two places here on Earth, Ennico Smith said: Ames and Brookhaven National Laboratory in New York. At Brookhaven scientists will expose the yeast to a high-radiation environment. Taken together, the data haul should help the team tease out which effects are due to radiation and which result from microgravity or other factors.

© NASA

Mysterious 'alien Neptunes' are probably water worlds

Words by **Charles Q. Choi**

Much remains hotly debated about sub-Neptunes, such as how they formed. Their compositions remain unknown, and understanding them could help shed light on exoplanets' origins.

Previous research suggested that sub-Neptunes were either gas dwarf planets with rocky cores surrounded by envelopes rich in hydrogen and helium, or water worlds with liquid and frozen water in addition to rock and gas. To investigate the make-up of sub-Neptunes, scientists ran simulations of planetary growth to see what scenarios might best explain the masses and diameters seen among exoplanets so far.

Knowing the mass and diameter of a planet can help astronomers estimate its average density, and simulations of planetary growth can help reveal whether compositions of gas, rock, ice or water might best explain these densities.

Researchers found that sub-Neptunes are more likely to be water worlds than gas dwarfs. They suggested that each sub-Neptune is at least 25 per cent, and possibly more than 50 per cent liquid or frozen water by mass. In contrast, Earth is only 0.02 per cent water by mass.

It remains a mystery why our Solar System lacks planets between Earth and Neptune in size, and why systems that Kepler has seen often have more planets closer to their stars than our Solar System does. Solving these puzzles might help shed light on how systems form.

Sub-Neptunes are more likely to have a watery composition

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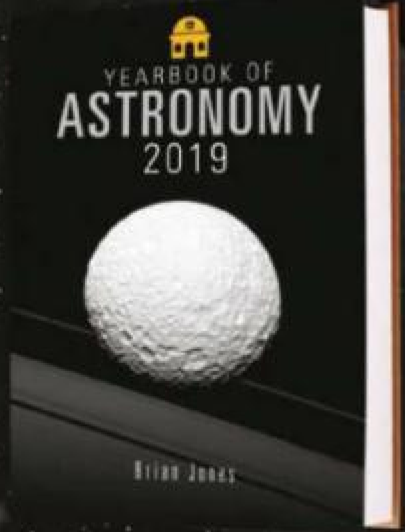

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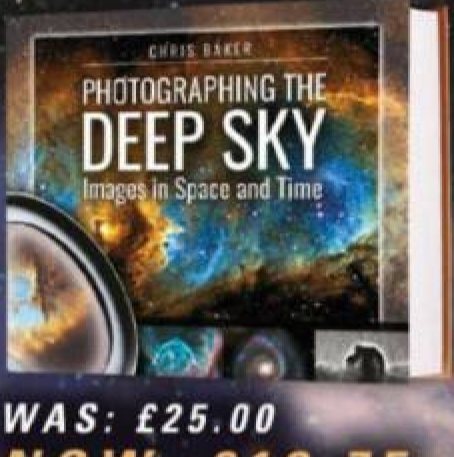

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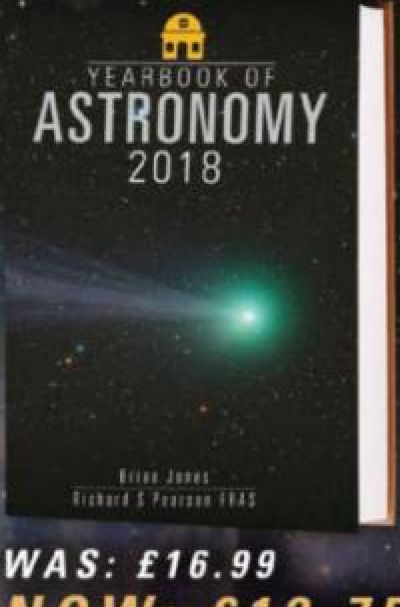

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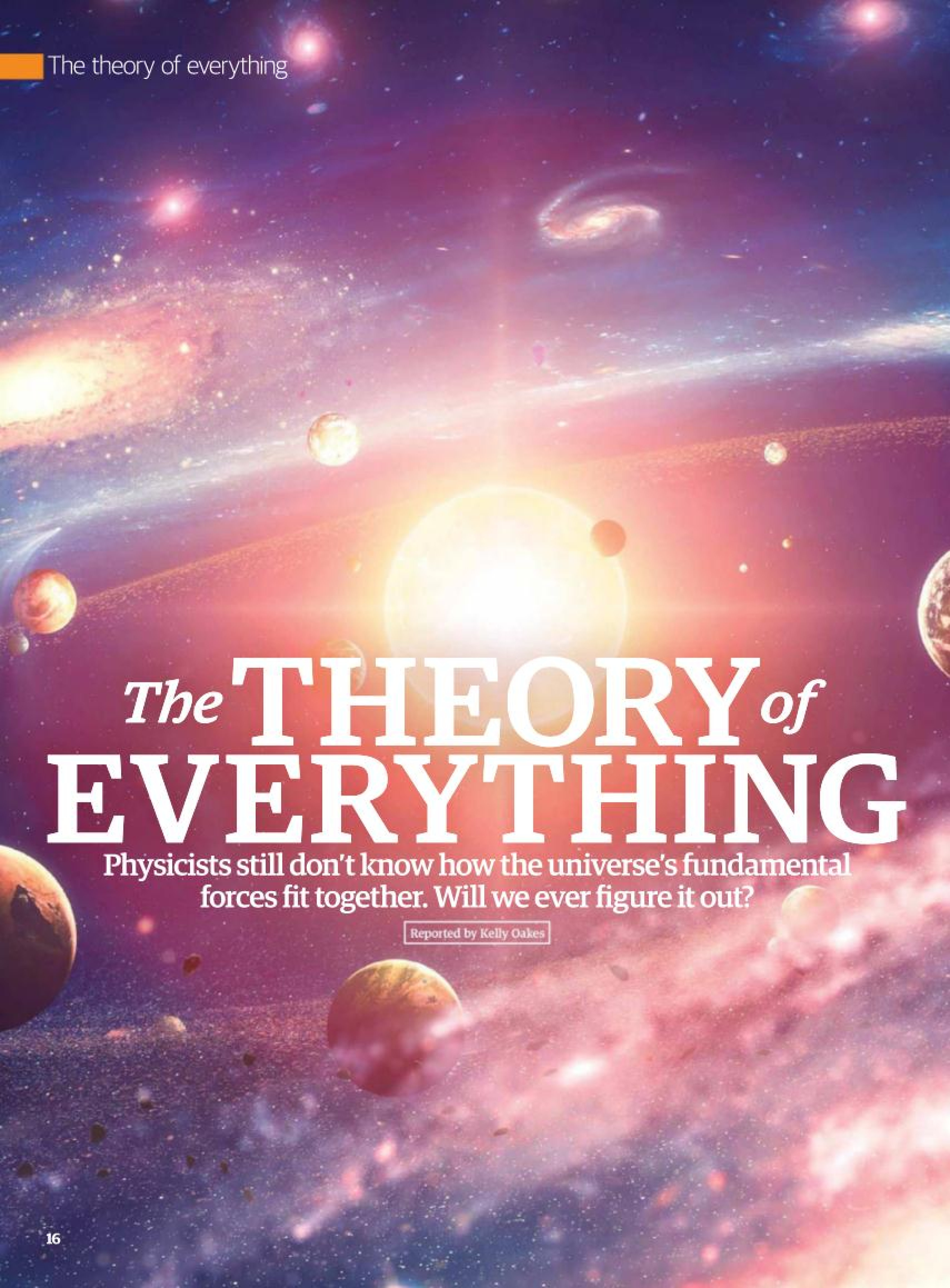


The THEORY of EVERYTHING

Physicists still don't know how the universe's fundamental forces fit together. Will we ever figure it out?

Reported by Kelly Oakes

© Tobias Roetsch

Earlier this year physicist Michio Kaku said he thinks we'll have a theory of everything by 2100. But what would such a theory even look like – and how likely is that to happen?

Physicists have a good understanding of how the universe works at a large scale. Albert Einstein's general theory of relativity explains the motion of the planets, the bending of light from distant stars and galaxies and the existence of black holes. We also know what's going on at a small scale. The Standard Model of particle physics has proved itself over the last few decades with the discoveries of the fundamental particles it predicts.

But there's a catch. These two theories don't sit well together. And there are some places – inside a black hole, and right at the beginning of the universe – where physics as we understand it appears to break down altogether. To go deeper and really understand

Artist's impression of two black holes merging and creating gravitational waves, as predicted by Einstein

how the universe ticks, physicists want to combine the two theories. But that's easier said than done.

General relativity says that the cosmos is made up not of three-dimensional space, but four-dimensional space-time, and that gravity arises from how this space-time is warped. Objects like the Sun and planets that have a lot of mass curve this space-time like a bowling ball would curve the surface of a trampoline. It's our best explanation of how gravity works, and superseded Isaac Newton's universal law of gravitation after Einstein first presented his theory in 1915.

Since then, Einstein has been proven right again and again. Just four years after he presented his theory, the total eclipse of 1919 provided the perfect experimental test. Total solar eclipses happen when the Moon fully covers the disc of the Sun from a certain point of view on Earth. General relativity had predicted that because the Sun is so massive and bends space-time so much, the light from a star visible behind the Sun would be deflected slightly - and that's exactly what scientists saw.

> "General relativity says that the cosmos is made up not of three-dimensional space, but four-dimensional space-time"

But gravity is only one of the four fundamental forces that govern the universe. It's actually the weakest of the four, but is probably the most well known because it has a - thankfully - noticeable effect on the scale at which we live, keeping our feet firmly on the ground. On smaller scales, however, it all but disappears.

The other three forces deal with the smallest physics in our universe: subatomic particles. Electromagnetism is responsible for light and the rest of the electromagnetic spectrum. The strong and weak nuclear forces, also called the strong and weak interactions, govern how atoms are held together and decay.

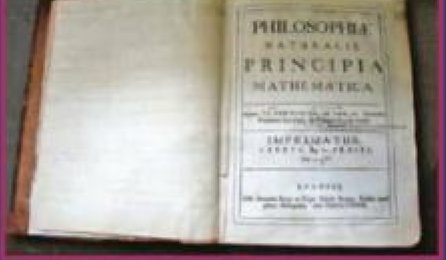
Together these three forces are described by what's known as the Standard Model of particle physics. The Standard Model as it is today was finalised in the 1970s, and in the years since the particles it predicted have all been discovered. The discovery of the last remaining particle - the Higgs boson, which confers mass to all other particles - was announced in 2012 by particle physicists at CERN in Geneva. When it comes to making all four of the forces in these two theories play nicely together, however, physicists have a problem. "These two theories don't cooperate well," says Sabine Hossenfelder, a theoretical physicist at the Frankfurt Institute for Advanced Studies in Germany.

From Newton to string theory

1687

Newton's law of universal gravitation

In his work *Principia*, Isaac Newton ties together Galileo's work on gravity, Kepler's laws of planetary motion and the phenomenon of tides in one law covering gravity throughout the universe.



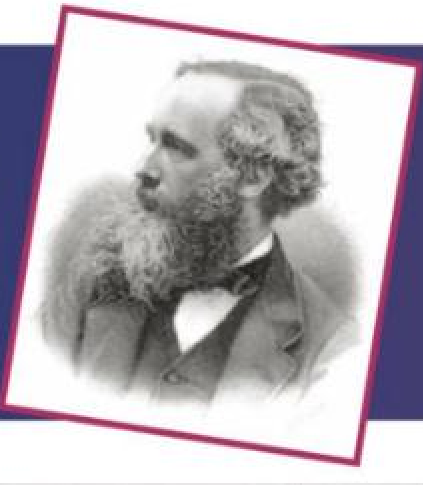
PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA

IMPRIMATUR

1865

Maxwell unifies electricity and magnetism

James Clerk Maxwell discovers that electricity, magnetism and light are three different aspects of the same phenomenon by showing that both electric and magnetic fields travel through space as waves.



What is the theory of everything?

The theory of everything needs to encompass all we already know about the universe

Theory of everything

The theory will have to bring together a lot of different aspects of physics, from Einstein's general theory of relativity that governs our understanding of the largest structures in the universe to the Standard Model that helps us understand the smallest particles.

Quantum gravity

Theoretical physicists working on quantum gravity are trying to combine quantum mechanics and Einstein's general theory of relativity. If they're able to do it, it will be the first step towards a theory of everything.

Space-time

Einstein's general theory of relativity combines space and time into one four-dimensional description of the universe, referred to as space-time. The idea is that objects with a lot of mass, like planets, curve space-time. General relativity is our best theory of how gravity works.

Electronuclear force

A grand unified theory would combine all three forces in the Standard Model: electromagnetism and the strong and weak interactions. There are several models that suggest such a force exists, but physicists are yet to see it in experiments. It's possible that early on in the universe there was a time when the three forces were not yet distinct.

Standard model of cosmology

Our understanding of the universe on a large scale comes from the standard model of cosmology, otherwise known as the Lambda-CDM model, which assumes that Einstein's general relativity is the correct model of gravity over cosmological scales. There are still some problems with it that need solving.

Standard Model of particle physics

The Standard Model combines three of the four fundamental forces of our universe: electromagnetism and the strong and weak nuclear forces. It also contains all of the elementary particles we know about, including electrons and the particles that make up protons and neutrons, or quarks, and tells us how they interact.

Strong interaction

Also known as the strong nuclear force, it binds fundamental particles known as quarks into protons and neutrons, and also binds those protons and neutrons into the nuclei of atoms. At very small distances it's 137-times stronger than electromagnetism, and a million-times stronger than the weak force.

Weak interaction

The weak interaction plays a big part in how atoms decay, and is responsible for the radioactivity of elements like uranium and polonium. It's also what keeps the Sun shining: the weak interaction is crucial for nuclear fusion, when elements inside stars fuse together and release energy.

Electroweak interaction

The weak interaction and electromagnetism are separate forces, but at high energies they combine. It's thought that there was a time in the early universe when the temperature fell enough for the strong force to separate out from the other two, leaving the electroweak interaction combined.

Electromagnetism

Electromagnetism is one of the four fundamental forces in our universe, and one of the three forces incorporated into the Standard Model of particle physics. It's responsible for electromagnetic radiation like light and microwaves, and the chemical bonds between atoms that join them up into molecules.

Electricity

Electricity – the kind that powers our light bulbs and phone chargers – is generated by charged particles such as electrons. It is one aspect of the electromagnetic force, but we didn't always know that was the case.

Magnetism

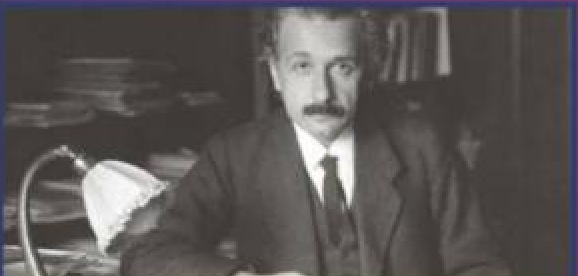
Magnetism is the force at play when you attach magnets to your fridge, or play around making patterns with iron filings in science class. Like electricity, magnetism is one aspect of electromagnetism.

© NASA; Andrew Dunn

1915

Relativity supersedes Newton's gravity

Albert Einstein's general theory of relativity, first presented in 1915, takes over from Newton's work as the best description of gravity we have. It describes gravity as a property of the curvature of space-time.



1929

Quantum mechanics enters the fray

After quantum mechanics – which reveals that light can behave as a particle and matter can behave as waves – takes off, Paul Dirac declares the underlying laws for most of physics and all of chemistry "completely known".

Far left (top): An image of a black hole - where the known laws of physics break down - taken by the Event Horizon Telescope

Far left (bottom): The Compact Muon Solenoid (CMS) at CERN

Left: Particle tracks in a chamber

Physicists have been able to combine quantum mechanics with special relativity, but combining it with the general form of the theory just doesn't seem to work. That's why theoretical physicists around the world are trying to come up with what's known as a theory of quantum gravity. Depending on the specifics, solving quantum gravity by itself might not be a theory of everything - but it would certainly be a big step towards one.

The most well-known idea to bring these two seemingly incompatible theories together is string theory. String theory is not just trying to bring together quantum mechanics and general relativity, but provide an entirely new way of looking at things. "[String theory] tries to unify all interactions and provide a theory of quantum gravity in the process," says Jorge Pullin, a theoretical physicist at Louisiana State University. In string theory the universe is not made up of particles, but instead one-dimensional vibrating strings, where different vibrations correspond to different particles. For this to work, string theory requires a universe with more than the four dimensions of space-time - up-down, left-right, forwards-backwards and time - we're used to dealing with.

Different versions of string theory have required different numbers of dimensions to work: the earliest version, called bosonic string theory, needed 26 dimensions. Later came superstring theory, which would need ten dimensions. Then a third version, called M-theory, brought several types of superstring theory together in 11 dimensions.

Another option, loop quantum gravity, is trying to combine general relativity with quantum mechanics while preserving as much of Einstein's theory as possible. Unsurprisingly given its name, loop quantum gravity uses the idea of a gravitational field made up of loops to do this.

"Most people are familiar with the concept of lines of force, like with magnetic fields they looked at in high school," says Pullin. "And so the equivalent of those lines for the gravitational field is more or less what these loops are about." Those loops can intersect and come together in what physicists call spin networks, and if you look at how those networks evolve over time you get what's known as spin foams.

Loop quantum gravity on its own wouldn't unify the four fundamental forces, and so it wouldn't be a theory of everything. "Our focus right now is on trying to understand gravity by itself, mostly," says Pullin. "We're not so concerned about unifying all interactions."

An intriguing possibility is that loop quantum gravity and string theory might be two different aspects of the same underlying mathematical framework. But so far that's just a suggestion, says Pullin. "I personally think there are certain aspects of string theory that look quite obviously correct," he says. "Similarly, there are certain aspects of loop quantum gravity that look right too. So my hope is that in the future the two theories will converge eventually, at least certain aspects of them."

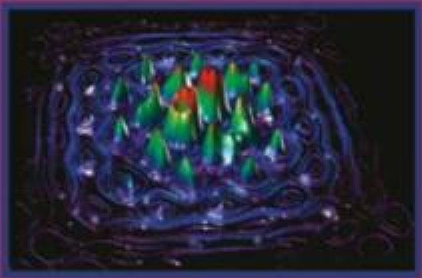
While string theory and loop quantum gravity are the two main contenders for a theory of quantum gravity based on the number of people working in each field, there are a few lesser-

> "My hope is that in the future the two theories will converge eventually, at least certain aspects of them" **Jorge Pullin**

1940s

Quantum electrodynamics

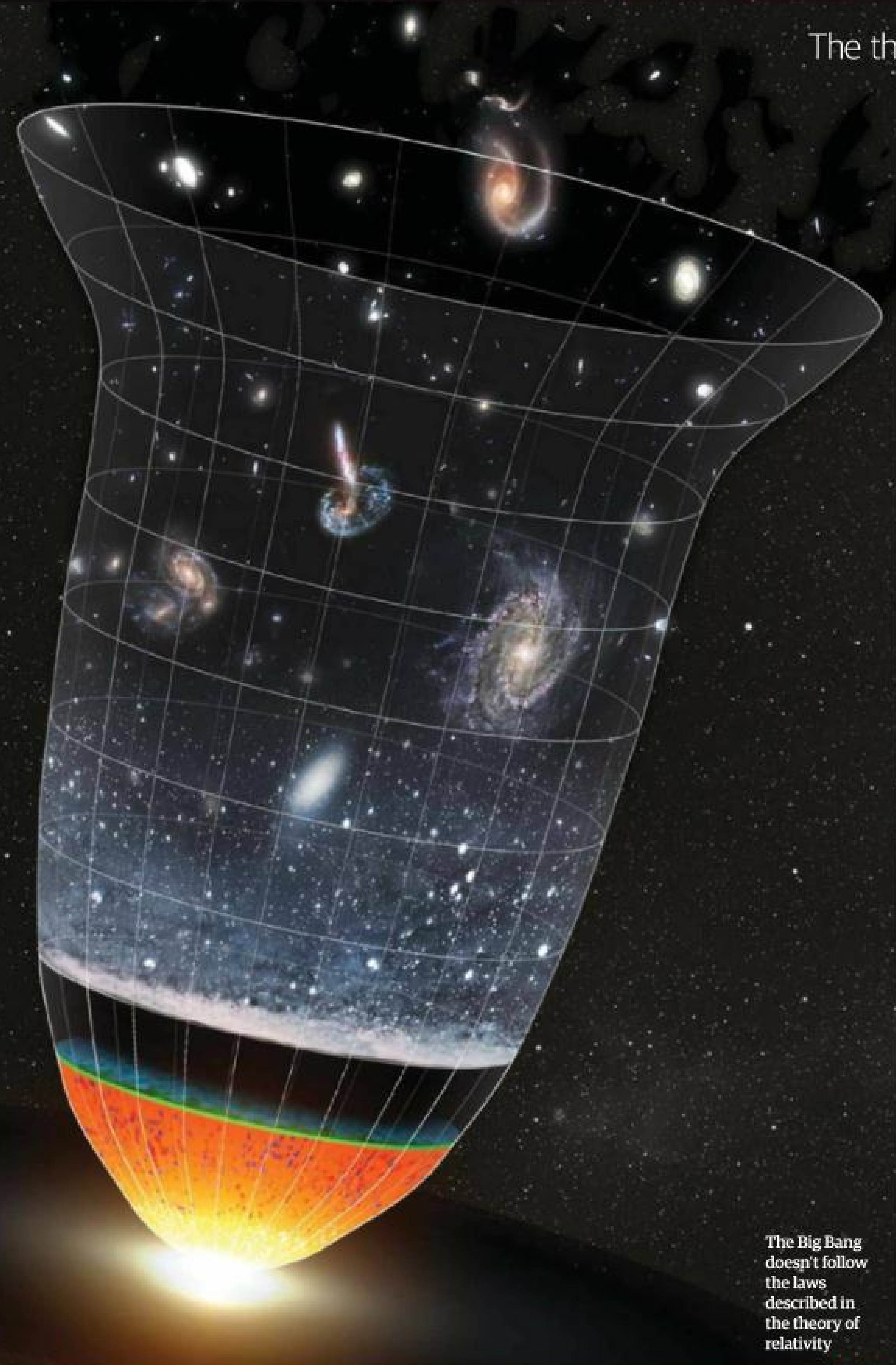
Physicists come up with the theory - which describes how light and matter interact - by applying quantum mechanics to fields instead of just particles. It's the first theory where quantum mechanics and Einstein's special relativity fit together.



1967

Electroweak interaction

Physicists figure out how to combine two of the four fundamental forces, electromagnetism and the weak nuclear force, into what's called the electroweak interaction. Sheldon Glashow, Abdus Salam and Steven Weinberg are awarded the 1979 Nobel Prize for Physics.



The Big Bang doesn't follow the laws described in the theory of relativity

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Can there really be a theory of everything?

Sabine Hossenfelder is a theoretical physicist at the Frankfurt Institute for Advanced Studies in Germany

What exactly do physicists mean when they say 'theory of everything'?

A theory which combines all the known fundamental forces. That's the electromagnetic force, the strong and weak nuclear forces and gravity.

Do you think we're likely to find one?

I think it is feasible. But the asterisk to that is that we would never really know that what we have is actually the final theory, because it could always be that tomorrow we discover something that does not fit in, and we need a new theory again.

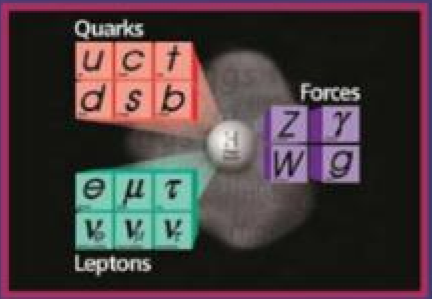
Would it really describe everything?

In principle you'd be able to derive all the other laws of the universe from it. If you could actually do that in practice is a completely different question. Even if we have a theory of everything, we may not be able do the necessary calculations.

1970s

Standard Model of particle physics

The current version of the Standard Model was finalised in the 1970s. It describes three of the four known fundamental forces: the strong and weak nuclear interactions and electromagnetism.



1986

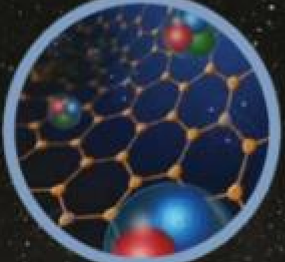
Coining the term

In an article on superstring theory – one possible route to a universal theory of physics – published in the journal *Nature*, physicist John Ellis coined the acronym 'TOE' for the phrase 'theory of everything'.

Solving the problem

Some of the theories behind finding the truth

String theory
String theory says that the cosmos is made up of one-dimensional strings which vibrate at different frequencies that correspond to different particles. It's a whole new way of thinking about the universe, and requires there to be extra, hidden dimensions - at least another six on top of the four that we are aware of - that we can't see.



Loop quantum gravity
Loop quantum gravity, or LQG for short, isn't aiming to be a theory of everything, but it could be a step on the path towards one. It's defining feature is that it tried to maintain as much of Einstein's theory as possible as it portrays the gravitational field in a series of loops, splitting space-time into indivisible chunks.

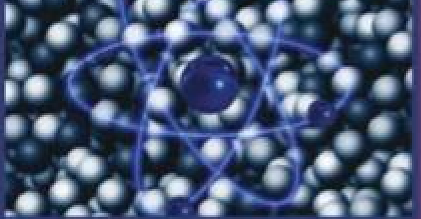
Causal sets
This idea says that space-time doesn't exist at all, but is just an approximation of the actual underlying fabric of the universe: a series of disconnected points. Though the points are distinct, they are related to each other causally - where one thing causes another to happen - hence the theory's name.

Asymptotically safe gravity
This way of uniting quantum mechanics and gravity involves using the same framework of the Standard Model, but applying some mathematical safety precautions to stop it misbehaving at high energies. It goes back to Steven Weinberg, who won the Nobel Prize in Physics for his part in finding the electroweak interaction.

CDT
Causal dynamical triangulation, shortened to CDT, involves making space-time out of lots of little triangular shapes - hence the name - instead of the smooth fabric it's described as in Einstein's theory. These triangles join together to make multi-dimensional triangles known as simplexes.

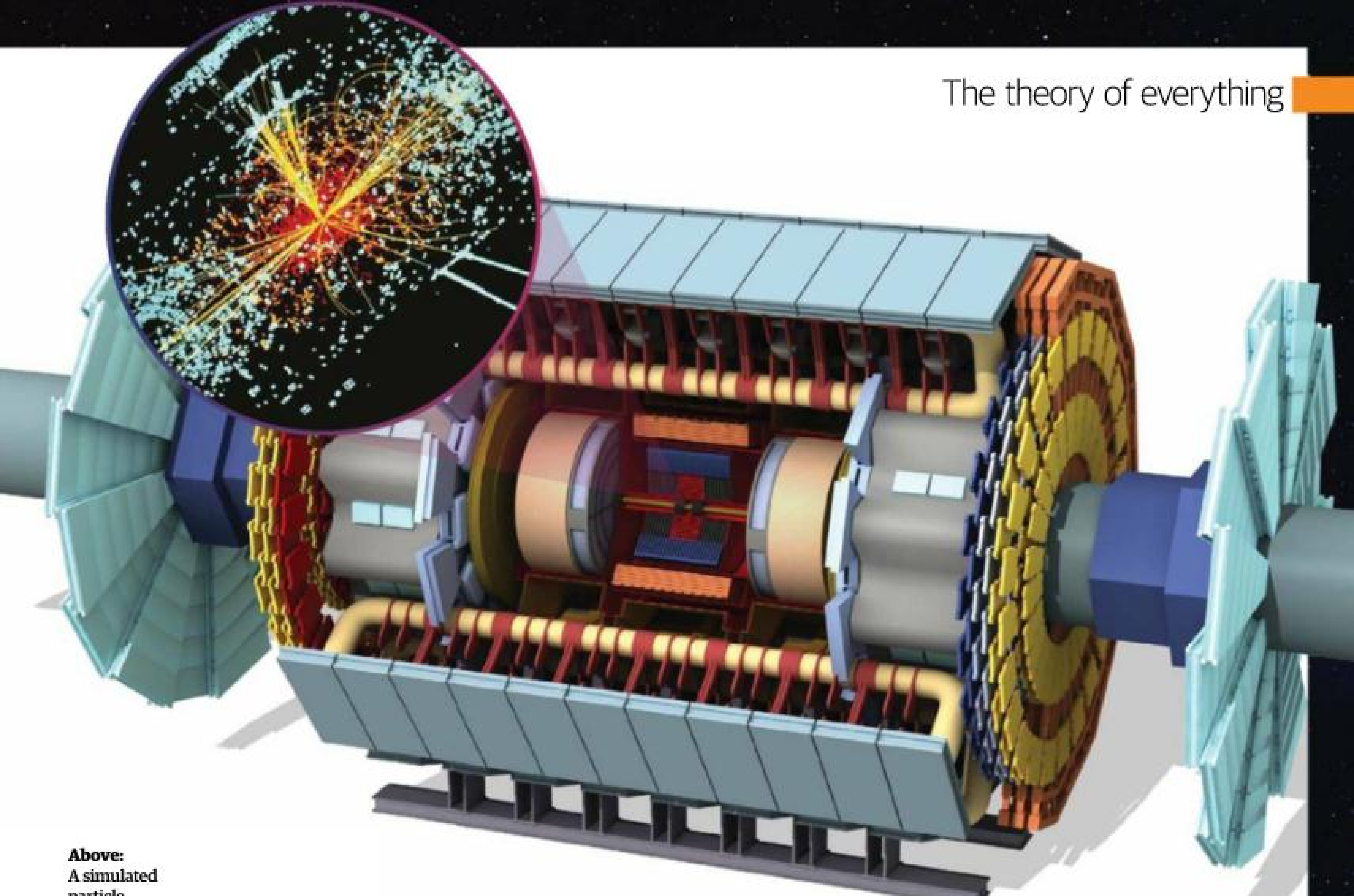
1990s

String theory steps up
String theory research steps up, and many physicists see it as the most promising candidate for a theory of everything. It replaces particles with one-dimensional objects physicists call strings.



2012

Higgs boson is found
The discovery of the Higgs boson, the particle that gives all other particles mass, is announced by particle physicists at CERN in Geneva. It's the last remaining particle needed to make the Standard Model complete.



Above: A simulated particle collision in the CMS experiment at the Large Hadron Collider, producing a Higgs boson

> "I think that right now we are still far away from finding this theory of everything" **Sabine Hossenfelder**

known ideas too. One, called causal dynamical triangulation, involves dividing space-time up into little triangles. Another is a theory called causal sets, which says that space-time is only an illusion, and the fabric of the universe is really a set of disconnected but related points. Asymptotically safe gravity is a perhaps more mundane idea, and involves quantising gravity using the same framework that results in the Standard Model, but applying some mathematical safety precautions to prevent the problems that will otherwise arise.

But quantum gravity isn't the only thing we need for a theory of everything. Another step is unifying the three forces in the Standard Model of particle physics: the strong and weak nuclear forces, and the electromagnetic force. We know that two of these, the electromagnetic force and the weak force, do come together at high energies as something called the electroweak interaction. But so far the strong force has remained steadfastly separate.

Theories that combine all three - known as grand unification theories, or GUTs - tend to require protons that are unstable and decay, similar to how atomic nuclei decay. But that's not what we observe in nature. "If you manage to closely monitor a lot of those protons, for example, just by taking a big tank of water, you can estimate how likely it is for proton to decay, even if it takes a very long time," says Hossenfelder. "And we have not seen a single proton decay." This has ruled out our first couple of attempts at a grand unification theory, she says. But there are other more complex versions that can't yet be ruled out experimentally, so could turn out to be accurate.

Similarly, one of the major problems with string theory is that we can't yet test it experimentally. "Because of this, I think that right now we are still far away from finding this theory," says Hossenfelder. "Even if we were able to solve those mathematical problems, in the best case maybe we'll be able to solve them in the next 20 years, we would still not know that this is actually the theory that describes the universe that we live in."

But, says Pullin, that's to be expected for theories that aren't fully unravelled yet. "The fact that we don't have experimental predictions for theories that are incomplete is not necessarily bad," he says. "Perhaps when we know more about them, the experimental prediction will come about."

Until very recently, says Hossenfelder, people had assumed that experimentally testing quantum gravitational effects was not possible at all. That's because, as the weakest force by a long way, the quantum effects of gravity are also much weaker than the quantum effects of the other forces. "Basically, the reason we cannot see the quantum effects of the gravitational field is that we cannot create large objects with quantum properties," says Hossenfelder.

It's a catch-22 situation. We can't measure these quantum gravitational effects for single elementary particles, because the effects are too small. And if you pile up too many of these particles, you have a higher mass - which would make it easier to measure those quantum effects - but then the quantum effects go away.

But there are new experiments on the horizon that could finally provide a way to measure quantum gravity, helping to point us in the right direction for a theory of everything. Over the last decade, physicists have been making headway with creating larger and larger objects that exist in quantum states. These objects are not yet big enough to allow physicists to also measure their gravitational effects - but with a few more technological advances, that's a real possibility.

Hossenfelder is hopeful that this means experimental tests of quantum gravity are within our grasp. And that would mean theorists working on string theory, loop quantum gravity and other quantum gravity theories could finally get an experimental nudge in the right direction. "If they actually manage to measure something, which I believe will be possible within, say, the next 20 years or so, then this has a lot of promise to actually guide the development of the theory," she says.

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INTERVIEW BIO

Seamus Tuohy

Seamus Tuohy is the principal director in charge of the civil and commercial space programmes at Draper Laboratory in Cambridge, Massachusetts, United States. Draper is a research and development organisation that has been around since 1932, playing a hand in the history of space exploration as it developed the Apollo Guidance Computer which took humans to the Moon.

Recently Tuohy has been overseeing development and testing of the Draper Multi-Environment Navigator (DMES) which, if successful, will allow autonomous landing on the Moon with minimal need for human operation.

Right: Buzz Aldrin and Neil Armstrong had to navigate themselves down to the Tranquillity Base by identifying lunar surface features

© NASA

THE FUTURE OF MOON LANDING TECHNOLOGIES

NASA and private enterprises are forever on the hunt for new initiatives to make lunar landings safer and more routine. Draper Laboratory is one of the organisations incredibly close to developing self-landing spacecraft

Interviewed by Lee Cavendish

How is Draper looking to improve and make lunar landings more routine?

Draper's making a rather large investment of time and energy in developing technologies for landing on the Moon very precisely and very safely. That ranges from small landers all the way up to landers that would carry humans down to the surface of the Moon and also very large cargo delivery systems which would carry habitation modules down to the surface of the Moon.

The technologies apply to all of the different sizes of landers, but all have to do with landing very precisely. It will navigate to where you want to be but also detect hazards that pop up while on your final approach, which you may not have seen through imagery, avoiding those, getting you to the surface and near as possible to your desired point.

A test was recently completed over Tuscon, Arizona. Please can you tell us a bit about what was involved?

So one of the challenges of developing technologies to land on the Moon is that it's a hard thing to do and you don't have a test Moon you can go to and try things out. So what you try to do is use the Earth as an analogue, to replicate some environment to incrementally stress your systems so that you build confidence in that performance before you actually go to the Moon.

The test we just recently did was one of those. It was testing a vision-based navigation system that we call DMES, for Draper Multi-Environment Navigator. A particular aspect of DMES we were testing was its vision using optical cameras – to track features while the vehicle was doing terminal approach and landing so that we could navigate. This test gathered data from a landing that started at 120,000 feet [37 kilometres] altitude. We had previously tested this system from being dropped from aeroplanes at about 35,000 feet [11 kilometres] to sub-orbital rockets that had gone up to 70,000 feet [21 kilometres]. This was just another stressing of the software and a camera system to see if it would work from 120,00 feet.

When we go to the Moon it will have to work kilometres in altitude, but the Moon is somewhat better as it has no atmosphere and no disturbances, so nothing to muck around with the picture. This was a very good incremental test, and what NASA provides through what they call Flight Opportunities is that NASA will make available a testing platform – in this case a high-altitude balloon – and Draper comes with its navigation instrument and software. NASA then allows it to be put up on the platform up to 120,000 feet [37 kilometres] and it gets dropped, and we get all the data from that drop test and we see if it works.

Are there any tests planned for the near future?

Yes. So we have tests on Earth which will go on a sub-orbital rocket developed by a company named Masten, and we also have tests to go up on a sub-orbital but space-capable rocket called New Shepard, developed by Blue Origin.

In two years we have the ultimate test in that we are going to fly the software on a commercial small lander that will actually land on the Moon.

What challenges need to be overcome when it comes to designing and creating the technology?

The initial challenge is developing the algorithms and matching them with the software and the hardware that develops the system. However, the biggest challenge is, like I said before, it's not very easy to go out and test it against the Moon. You have to do a lot of simulations, and Draper has invested a significant amount of money in gathering digital data of the Moon, collected by

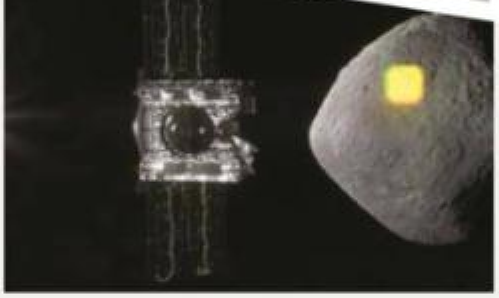
Right: Blue Origin's New Shepard will soon carry DMES as part of a future test

© Blue Origin

Right: NASA's Lunar Reconnaissance Orbiter has been at the Moon since June 2009

Below: The high-altitude balloon that saw Draper test its technologies at 120,000 feet (37 kilometres)

Bottom: Draper's autonomous navigation software will allow OSIRIS-REx to touch the surface of the asteroid Bennu and collect a sample



"This provides the technology that we believe will make lunar landings routine, reliable and safe"

NASA's Lunar Reconnaissance Orbiter [LRO], and digitising it. We can utilise it by modelling what the cameras would see when they go to the Moon.

But that is still done in a facility; the next-level tests are the ones we're doing now with the balloons and sub-orbital rockets where you actually take it out on the field and test it against what I would call 'real terrain' - things that have shadows, things that have different variations in how they look, different lighting conditions... just real world conditions. And that's the next step before you take it all the way to the Moon.

The Moon has been extensively imaged with orbiters and ground-based telescopes. What obstacles could appear that haven't already been imaged?

A hazardous obstacle to us is defined by something that the lander would have to avoid, either because the landing field is harsh or the platform isn't big enough. So if I'm landing something that has, for example, a ten-foot [three-metre] clearance of the ground, I can take obstacles that are a few inches or I could take stuff that's even a foot. That doesn't bother me because I'll clear it, but if I'm landing a small lander, then an obstacle that is a foot long could be really bad.

The data recorded by the LRO tends to be around three to four feet [0.9 to 1.2 metres] in resolution. Anything smaller than three to four feet may not be apparent in the images that you see.

You also have the situation where if you're landing at places that perhaps when the images were taken were in shadow - for example if you're at the south pole - then at the time you are coming, you need to detect obstacles and avoid them. It's essentially trying to do with a centring software system what Armstrong did when landing on the Moon for Apollo 11. He and Aldrin, a lot of what they did was hazard detection and safe landing site selection.

What's the importance of having technology that can do this in real-time as opposed to being remotely controlled from Earth?

The dynamics of landing are such that you'd like to have that rapid reaction in the ability of the platform itself to figure out where the safe spot is to put down. It adds to safety and it adds to reliability because you're taking elements out of the loop.

For example, if you want to land on the far side of the Moon you have to depend on relay systems to communicate back to Earth if you want to do it remotely. In the case of the technology we're developing, it has a high level of autonomy and you wouldn't have to burden the infrastructure necessary to do a landing anytime and anywhere on the Moon.

© NASA; World View® Enterprises; Draper

Could this technology be applied to regions beyond the Moon?

Yes. Some of the work we are doing is built upon the work we are doing with [NASA's] OSIRIS-REx, which is a mission orbiting an asteroid right now and attempting to touch down and collect a sample. Some of the navigation technology we are leveraging here was developed for that programme, where we are helping to navigate the spacecraft to the precise sample-collection point.

It also has direct application to any planetary body, whether that's an asteroid, a moon of another planet that doesn't have an atmosphere or a planet that doesn't have an atmosphere. The navigation system depends on being able to detect features and using the machine vision software to determine how those features move within the picture which you take so that you can determine where you are, how fast you're travelling and also to detect things that would be hazardous to your landing.

The 50th anniversary of the Apollo 11 landing is imminent. How does this technology compare to that used at the time?

Draper was the first contractor named on Apollo. We developed the Apollo navigation system and the guidance system. We're very familiar with that technology, and we tend to think of the system as navigation - determining where you are - guidance - where I want to go - and control - how you control the platform to get to where the guidance says.

Control is very vehicle-specific; it's how you fire jets and control thrusts to move your vehicle. The Apollo guidance system was actually very sophisticated in order to do that, so we're leveraging that technology. Guidance is very physics-based, and as physics hasn't really changed in 50 years we're leveraging a lot of the same techniques used on Apollo. Navigation is where the big change is. For Apollo it depended, particularly on landing, on the astronauts to do navigation relative to features they had identified and hazard detection and site detection. What we're trying to do here is - in order to make lunar landing more routine, safer and more reliable - we're adding autonomy to that navigation part. In addition to using the astronaut's eyes as a sensor, we're going to use cameras.

We're going to use modern sensing abilities and modern machine learning software to do the job if no crew is on board, but if the crew is on board, to augment the crew's ability in order to navigate relative to features and get very precise landing capabilities. Small landers, and even up to the large cargo landers would use modern optics, modern electronics, modern machine vision and machine learning to do the job that we require an astronaut to do.

What benefits does this type of technology have on the lunar lander business market?

What this does is provide the technology that we believe will make lunar landings routine, reliable and safe. This means the vehicle will get down to where you want it and it will get down in one piece in an operational landing.

In order to have commercial operations, you need something reliable. If I'm spending the money to start harvesting water ice in the south pole of the Moon, or I'm spending the money to extract rare-Earth material from the regolith of the Moon, I can't have landings that are special every time. It needs to be something that's routine, that's dependable, that's reliable, that I can count on happening to my desired requirements.

In particular, in being able to land precisely. Let's envisage a world in which I have mining operations on the surface of the Moon. When I extract something, I put those in some container that needs to be returned back to Earth. Well, I need landers that have either the supplies or the vehicle to take the material back to Earth. I have to have those land close to where the material is. If they land miles away then it doesn't do me any good, and I'll have the expense of having to transport stuff over to where the landers are. It's much better to have the landers land where they are supposed to land, and so from a commercial enterprise we think that this technology is critical to routinise lunar landings. So when they become routine all of a sudden you can start to depend on them, all of a sudden it becomes a known quantity, all of a sudden this is when you can start saying this is how I make my money.

Do you think this sort of technology takes away the need for astronauts, making the need for human exploration redundant?

In the aspect of landing precisely and safely it's not that you're replacing humans, it's that you're actually allowing humans to commute to work. You need humans to do the work. It's like saying if I had an autonomous car, then people no longer need to go to work. All the autonomous cars and trains do is allow humans to be in professions in which they are supposed to be working in, as opposed to me being the train conductor on my commuter train.

If these vehicles can land very routinely without humans, then why do we need humans? Well, we need humans to do the work that they were sent there to do, which is to explore, discover and put in place infrastructures and properties that you can eventually make money off. There's still a lot of complex operations that benefit from having humans there. We are just making the trip safer.

Above: World View Enterprises allowed Draper to take its vision-based technologies to space and capture the curvature of Earth

Left: Infrastructure on the Moon will require routine deliveries of equipment and facilities

MYSTERIES OF THE UNIVERSE

WHAT IS THE GREAT ATTRACTOR?

Galaxies appear to be affected by a concentration of matter, but what is it and where is it coming from?

Reported by David Crookes

© Tobias Roetsch

They became known as the Seven Samurai – seven astronomers dedicated to discovering more about elliptical galaxies who, in the process, appeared to slice through conventional theory. Drawn from across the globe in 1980, these seven were led by Sandra Faber. In her team were astronomers Alan Dressler, Roberto Terlevich, Donald Lynden-Bell, Gary Wegner, David Burnstein and Roger Davies. They were tasked with working with data collected by some of the most advanced giant telescopes on Earth.

The group had come together following some remarkable discoveries over the preceding two decades. One had come in 1965 when Arno Penzias and Robert Wilson, two researchers with Bell Telephone Laboratories, had picked up uniform noise from a radio receiver they had created. It was subsequently identified by a team at Princeton University as cosmic microwave background (CMB), the leftover radiation from the Big Bang.

But if that wasn't enough of a breakthrough, subsequent detailed mapping of the CMB in the 1970s led to another curious discovery. Astronomers knew that some 13.8 billion years ago the universe emerged from a singularity in an event that we know as the Big Bang, and that it has been expanding since. But the CMB was noted to be a little bit warmer on one side of the Milky Way than the other, and this finding proved to be a rather significant one.

For not only does the difference in temperature suggest the Milky Way is travelling at 600 kilometres per second (370 miles per second) relative to the cosmic background radiation – our peculiar velocity – it also led to research that suggested a rather lopsided movement. The galaxies on either side of the Milky Way were not seen to be travelling at the same velocity, pointing to a particularly large clump of matter exerting a strong pull.

Since this was discovered by the Seven Samurai, scientists have tried to pin down exactly what that might be and why the Milky Way – together with 100,000 other galaxies – is moving rather quickly towards an unseen object 250 million light years away in the direction of the constellations of Centaurus and Hydra. It's a gravitational anomaly and the findings suggest a cluster of galaxies with the mass of a quadrillion Suns somewhere out there is causing the effect. And yet none that are large enough have so far been identified with total conviction.

Dressler, who is now an astronomer at the Carnegie Institution for Science and working in the observatories in Pasadena, California, wants to get to the bottom of the issue. Having been part of the original team who made the initial discovery, he is today among a number of scientists continuing to look for evidence.

Such astronomers know the exact temperature difference – "the anisotropy amounts to +000335 degrees Kelvin on one side and -0.00335 on the other, so it's several thousandths of a degree warmer on one side and colder on the other side as seen from the Milky Way," Dressler explains – but they also have a bunch of other measurements to hand which they hope will point them in the right direction.

"Back in 1980 we had been taking measurements from observatories around the globe, looking to understand the structure of elliptical galaxies and when they formed," Dressler tells us, with reference to the original discovery. "We were taking measurements knowing that the universe is expanding and that the galaxies are moving away from each other. We knew we could get a pretty good idea of how far away a galaxy is by measuring how fast it is moving away."

The team also used a second method of finding distances to elliptical galaxies: looking at the

"We knew we could get a pretty good idea of how far away a galaxy is by measuring how fast it is moving away" **Dr Alan Dressler**

Right: The Great Attractor is pulling the Milky Way towards the southern constellations Centaurus and Hydra

The theories

It's a lure like no other, so what could be causing such a cosmic attraction?

Lure of gravity

The Great Attractor is referred to as a gravitational anomaly – if it wasn't pulling on the Milky Way and scores of other galaxies in this region, they would be continuing to fly apart. The crucial question is what is exerting that gravitational pull?

Virgo Supercluster

The Virgo Supercluster contains the Virgo Cluster and, importantly, the Local Group, which includes the Milky Way and Andromeda galaxies and their satellites on its outskirts. However, the supercluster is not massive enough to cause the pull.

Something hidden

A chunk of the universe is blocked from view by the gases, stars and dust of the Milky Way, and it just so happens that the Great Attractor is located in this chunk. Modern techniques have uncovered evidence of the Norma Cluster, which could be a pull.

Shapley Supercluster

This supercluster is also known to be in this area of the sky. It is about 650 million light years away and forms the largest nearby concentration of galaxies. Some scientists believe that may be causing the lopsided movement of our local galaxies.

A single location

There is thought that the Great Attractor is the gravitational heart of the Laniakea Supercluster, of which the Virgo Supercluster forms an arm. If this proves true then the Great Attractor is not a mass of objects, but a destination.

© NASA/ESA/JPL-Caltech; Nicholas Forder

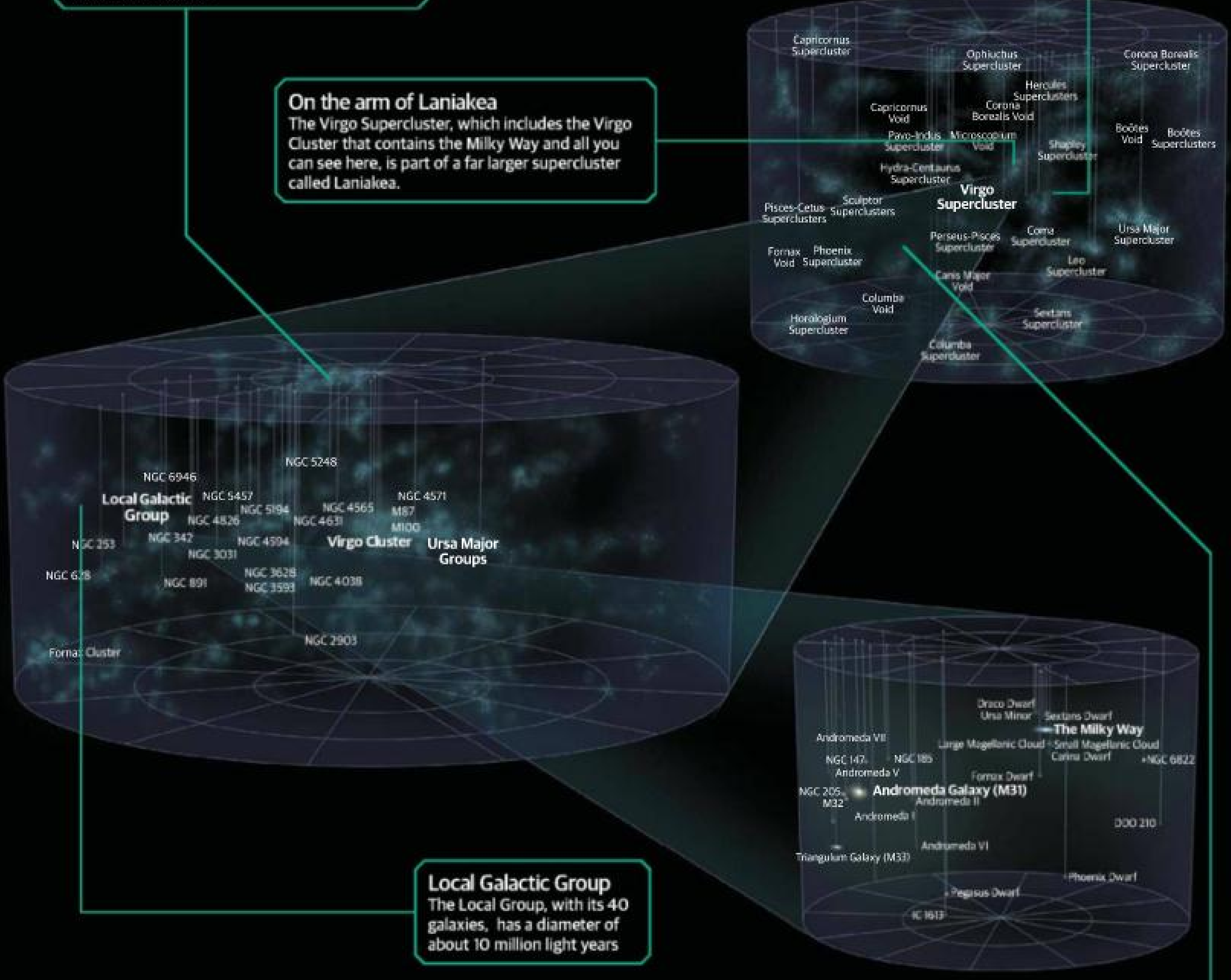
The Great Attractor: where it's located

As well as questioning what the mysterious force is, scientists have been seeking to pinpoint its location

Towards the Centaurus Cluster
The Great Attractor is a dense region about 220 million light years away, and it exerts its pull on the Milky Way and other galaxies in the Virgo Supercluster in the direction of the Centaurus and Norma clusters.

Virgo Supercluster
Containing the Virgo Cluster and Local Group, this Supercluster is 110 million light years across

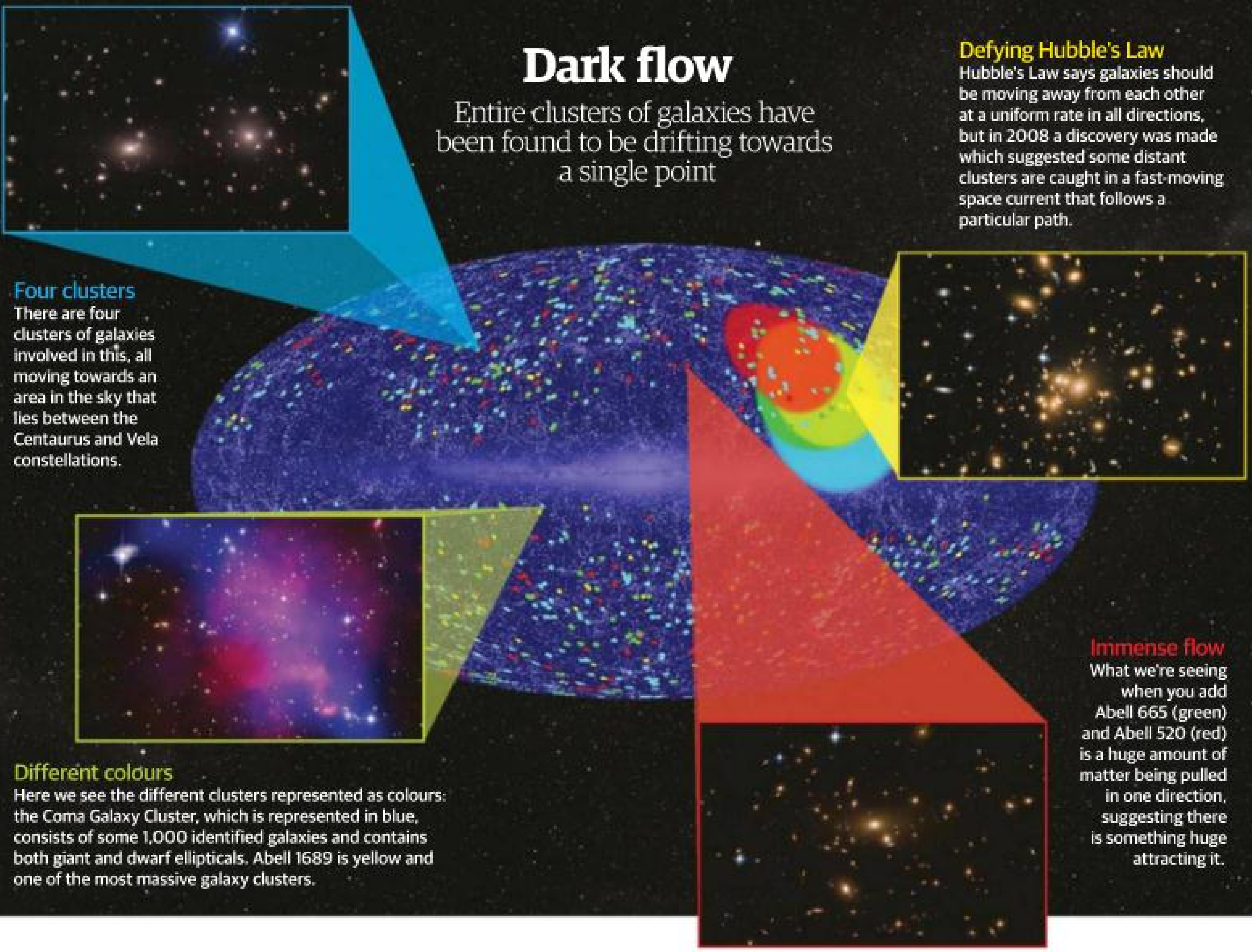
On the arm of Laniakea
The Virgo Supercluster, which includes the Virgo Cluster that contains the Milky Way and all you can see here, is part of a far larger supercluster called Laniakea.



Local Galactic Group
The Local Group, with its 40 galaxies, has a diameter of about 10 million light years

Laniakea's sheer size
At about 500 million light years in diameter, the Laniakea Supercluster is certainly huge. The Great Attractor is thought to be at its gravitational centre.

Superclusters aplenty
The Laniakea Supercluster borders another supercluster called Perseus-Pisces. It's an area of space that is densely packed with superclusters, and these will be exerting an immense gravitational pull.



Dark flow

Entire clusters of galaxies have been found to be drifting towards a single point

Defying Hubble's Law
Hubble's Law says galaxies should be moving away from each other at a uniform rate in all directions, but in 2008 a discovery was made which suggested some distant clusters are caught in a fast-moving space current that follows a particular path.

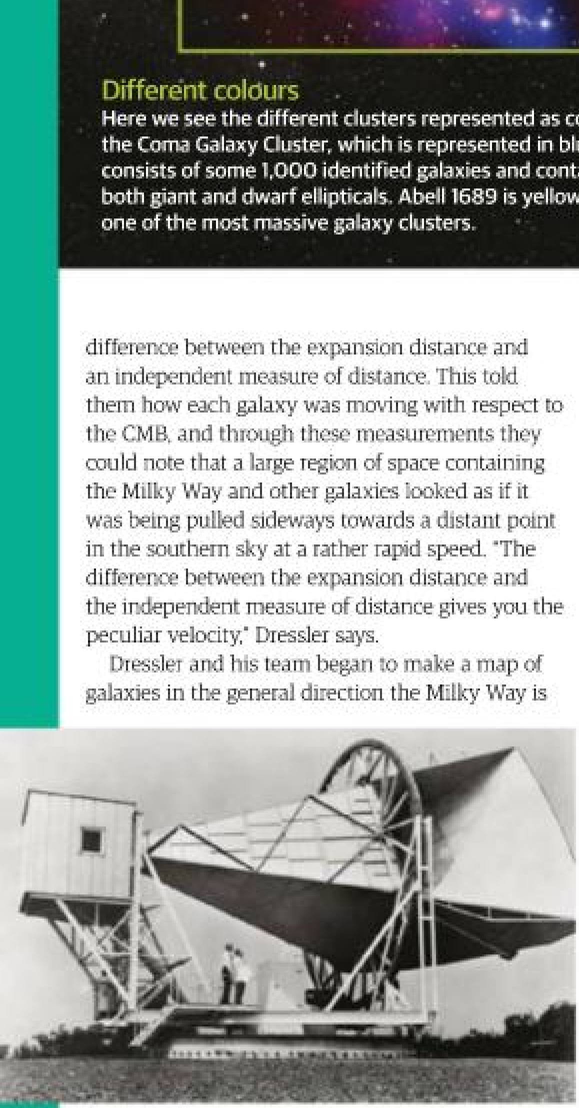
Four clusters
There are four clusters of galaxies involved in this, all moving towards an area in the sky that lies between the Centaurus and Vela constellations.

Different colours
Here we see the different clusters represented as colours: the Coma Galaxy Cluster, which is represented in blue, consists of some 1,000 identified galaxies and contains both giant and dwarf ellipticals. Abell 1689 is yellow and one of the most massive galaxy clusters.

Immense flow
What we're seeing when you add Abell 665 (green) and Abell 520 (red) is a huge amount of matter being pulled in one direction, suggesting there is something huge attracting it.

difference between the expansion distance and an independent measure of distance. This told them how each galaxy was moving with respect to the CMB, and through these measurements they could note that a large region of space containing the Milky Way and other galaxies looked as if it was being pulled sideways towards a distant point in the southern sky at a rather rapid speed. "The difference between the expansion distance and the independent measure of distance gives you the peculiar velocity," Dressler says.

Dressler and his team began to make a map of galaxies in the general direction the Milky Way is moving and found there was a big supercluster - a band of galaxies covering the southern sky, almost like an edge-on galaxy made of galaxies. They studied this further, running into the possibility that the universe was lumpier in its distribution of galaxies than ever imagined.



"Even though the universe expands in this sort of wonderfully uniform way, we also know it is very lumpy," Dressler affirms. He told an audience gathered to hear the group's findings in 1987 that the probable cause was a mass he dubbed the Great Attractor... the name stuck.

Since then astronomers have sought to figure out exactly what it could be, and within three years Dressler and the rest of the Seven Samurai had identified 139 galaxies influenced by whatever is out there. One of the major issues, however, is that it lies in a part of space that cannot be directly observed without difficulty.

This section of the sky is called the Zone of Avoidance, and the constellation Centaurus - the direction in which the Great Attractor lies - is right within it. It is an area obscured by the attenuation, stars and interstellar dust in the plane of the Milky Way, and this makes it near-impossible to see far in the visible spectrum. It means the evidence is based upon observing the movement of galaxies around it, although advancing observation techniques over the years have thrown up some possibilities.

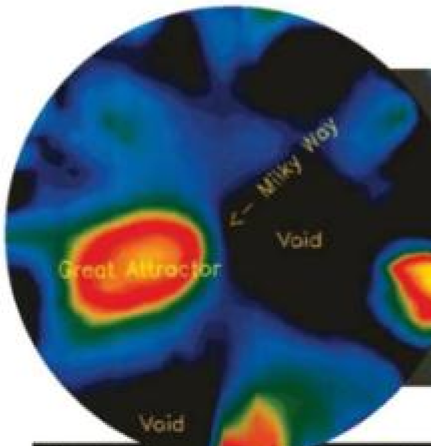
"At least one rich cluster has been identified in this region: the Norma Cluster," Dressler says. Indeed, the massive Norma Cluster has been discovered to be near the centre of the Great Attractor, and there is evidence that local galaxies motion towards it. Yet it doesn't tell the full story because the level of attraction is not on the scale displayed by galaxies such as ours - that is, until more evidence is uncovered. Notably, there is also a cluster called Virgo which has more than 1,300 galaxies in it, and as many as 2,000. It forms a part of the Virgo Supercluster, as does the Local Group which includes the Milky Way and Andromeda galaxies.

"The Virgo Supercluster is partly in the right direction to be pulling us, giving us a motion with respect to the CMB," Dressler says. "We live on the outskirts of this supercluster, and there has been a suggestion that it is pulling on us and holding us back." In that sense, the Great Attractor would easily be the Great Supercluster. "The fact that it isn't is more of an accident than anything else," Dressler says. Even so, that doesn't quite fully explain what is going on. "It made total sense, but people said: 'Yes, and where's the rest coming from?' We suggested that this big collection of galaxies - thousands of them - with their dark matter was enough to explain the Milky Way's motion with respect to the CMB, and we explained what needed to be added to the pull of the Virgo supercluster, which is ten-times smaller. We'd found a supercluster where we needed it and we made measurements of galaxies moving in that direction, but the data was not good enough from the technique used to convince our colleagues that the Great Attractor was the culprit," Dressler continues.

"So what happened in the years after that was a bunch of surveys being done where people said they were not sure about this Great Attractor, and let's see if we can find something further away - maybe a supercluster in the same general direction; a Giant Attractor, if you like."

It's certainly the case that astronomers have been looking for potential superclusters that could explain the attraction. There is consensus that a supercluster may be made up of galaxies that are being attracted to a common centre and, indeed, even the Virgo Supercluster does not exist alone - it has been found to be part of the Laniakea Supercluster, and the former is a mere appendage of the latter. The Great Attractor is understood by a number of scientists to be at the gravitational centre of the Laniakea Supercluster.

"There had been a conclusion that the CMB signals that we started with were not caused by Virgo and this Great Attractor, but something much further away which is even bigger," Dressler says.



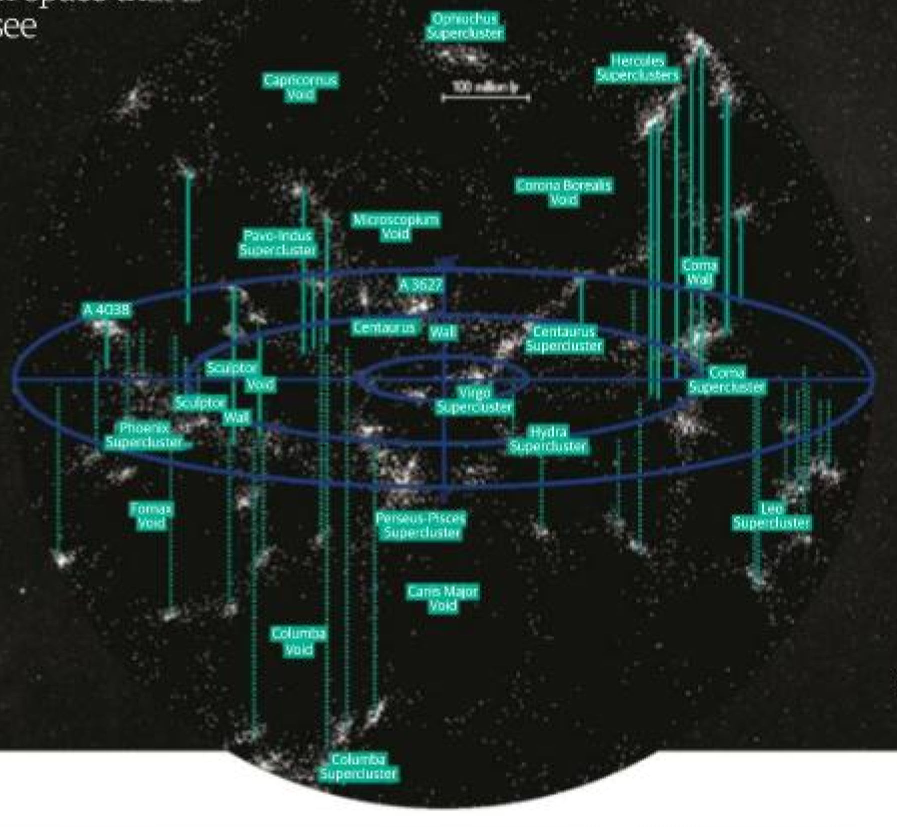
Top left: The Milky Way being pulled towards the Great Attractor as envisaged by a computer-generated image centred on the distribution of matter

Top right: A tiny area of the sky centring on a bright galaxy in the general location of the Great Attractor

Bottom: Taken by the Hubble Telescope, this image shows the region of the sky where the Great Attractor is located

The Zone of Avoidance

Its name sounds dramatic, but there is a section of space that is rather difficult to see



Zone of Avoidance

There is a 20 per cent chuck of the universe that obstructs the view of astronomers at visible wavelengths. This is what is known as the Zone of Avoidance.

Obstructed view

Viewing from the Milky Way, interstellar dust and stars in the galaxy's plane get in the way. From this galactic plane the Zone of Avoidance spans ten degrees above and below.

Redshift measurements

Astronomers are able to see 80 per cent of the universe around us, and they mathematically measure a parameter called redshift which allows them to figure cosmological distances.

Gathering data

The best way of observing objects in this zone is to make use of wavelengths unaffected by dust, such as infrared and X-ray surveys.

Multiple objects

Far from being free of extragalactic objects, this area of sky is full of objects and the Great Attractor is located within the Zone of Avoidance.

© NASA; ESA; ESO; Nicholas Forder; Adam Block/Mount Lemmon SkyCenter/University of Arizona

Left: An infrared camera on the Giant Magellan Telescope can measure galaxy distances to greater accuracy

"There had also been a theory that yes, it's the more distant thing that's pulling on us because not only is our galaxy moving, but even the Great Attractor is moving towards the more distant place. This happened around the year 2000 and the ideas conflicted with what could be measured from the microwave background."

> "Even though the universe expands in this sort of wonderfully uniform way, we also know it is very lumpy" **Dr Alan Dressler**

By the middle of that decade, however, further work was carried out. The Parkes radio telescope was fitted with a new receiver aimed at peeking past the Zone of Avoidance. The HI Parkes All-Sky Survey has been able to map the sky 13-times faster than before and hundreds of galaxies - a third of which had never even been suspected - have been revealed. The density of galaxies in this area of the sky is becoming better known, and yet the Great Attractor itself has still not been found.

In 2010, Dressler returned to work on the Great Attractor to determine if he could make some headway in clearing up the mystery. "There was a new technique for getting galaxy distances which I had worked a little on in 2000 where you try to resolve the brightest stars in the galaxy," he says. "You can measure the brightness fluctuations to a much better degree than we were able to do back in the 1980s.

"We have an infrared camera on the Giant Magellan Telescope and it takes cosmetically perfect pictures. This means that compared to earlier techniques distances can be measured to ten per cent accuracy instead of only 25 per cent, and that is making it possible to settle the matter of whether the Great Attractor, or something more distant, is responsible for the CMB dipole anisotropy seen from the Milky Way."

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Dressler's hunch is that gravity is simply at work in a hidden cluster of galaxies, and indeed, Paul Sutter, an astrophysicist at The Ohio State University, wrote on our sister site **space.com** that we may well be seeing galaxies such as ours heading towards the centre of the Local Group. In turn, he writes, the objects in the Virgo Supercluster are falling towards its own centre: the Virgo Cluster. Similarly, the Laniakea Supercluster is condensing into its centre where the Norma Cluster resides. What's more, in 2016 hundreds of galaxies discovered by Australian astronomers 250 million light years away were shown to have an immense gravitational pull, and could be the source.

There is, however, still a lot of work to do. "I'm studying galaxies on both sides to get their distances and their motions and other people are using other methods to find other galaxies behind this galactic dust," Dressler says. "But from most of the Great Attractor - the part we can see - there is only the Centaurus cluster which is far from the centre and this Norma cluster which is closer to the centre. Most superclusters have several very populous clusters of galaxies within them, so the Great Attractor just looks different in that way."

The likelihood is that gravity is simply at play, and there are plenty of galaxies in the Great Attractor to do the pulling. "Not having several giant clusters of galaxies as most superclusters do caused other people to doubt that the Great Attractor was responsible," he adds. "But I'm making measurements of distance and motions to show that the heart of the Great Attractor is not moving with respect to the CMB, which means it is the source of the gravity that gives the Milky Way and its neighbours their motion."

So why is all of this important? Well, aside from the scientific value in being able to explain the observed phenomenon, it has also been noted that whatever is causing the Great Attractor is moving away from us at a slower rate than it should, which would mean there is a chance that our galaxy will eventually reach it, and perhaps it will destroy us. It's not something to be worrying about today - that's for humans a few billion years from now to fret about - but it's intriguing nevertheless. Attraction can be destructive, after all.

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"One small step for A man, one giant leap for mankind", words spoken by Neil Armstrong, the first human to walk on the moon. Those moments of the 21st July 1969 will resonate, entertain and inspire generations to come.

2019 celebrates the 50th anniversary of the Apollo 11 landing, which is responsible for the first foot prints on the moon, which still remain there to this day. Corgi are proud to reintroduce two Apollo 11 products to the range in celebration of this scientific feat.

Chief designer of the rocket is Long Lehao

USER MANUAL

Long March 5

China's most powerful rocket will bring the nation's presence in space to prominence, eventually building a space station

THE SPECS

Launch: 3 November 2016

Launch site: Wenchang Launch Center, Hainan Island

Rocket: 57 metres (187 feet) by 5 metres (16 feet)

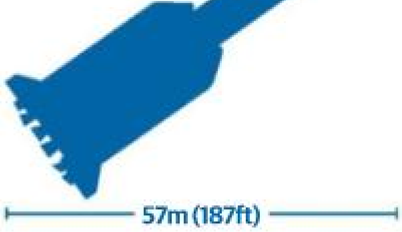
Target: Low-Earth orbit and beyond

Operator: China Academy of Launch Vehicle Technology (CALT)

Capacity to low-Earth orbit: 25,000 kilograms

Components: Two core engines and four boosters

Next launch date: July 2019



The Long March 5, or Changzheng 5, is supposed to become the crown jewel of Chinese rocketry. The China Academy of Launch Vehicle Technology (CALT) has been working tirelessly over the last two years to perfect one of the world's most powerful rockets, which is comparable to the United States' Delta IV Heavy. The Delta IV Heavy rocket, which most notably launched NASA's Parker Solar Probe in August 2018, provides a total thrust of 9,700 kiloNewtons (kN) that can take roughly 28,970 kilograms (63,471 pounds) of cargo to low-Earth orbit. To put the Long March 5 into perspective, this rocket provides 5,840 kN of thrust at sea level and can place around 25,000 kilograms (55,116 pounds) of cargo into low-Earth orbit. This makes the Long March 5 the third most powerful rocket currently on the market, with the Delta IV Heavy in second and SpaceX's pioneering Falcon Heavy reining supreme.

This rocket was built with the aim of satisfying China's demands for transferring large payloads into low-Earth orbit, geostationary transfer orbit (GEO) - which is a more elliptical orbit around Earth - and farther in the foreseeable future. Since 2007 when funding began, the rocket has been constructed from the ground up, and has so far had its highs and lows in demonstrations. It has only undergone two flights: the first was in November 2016, which was deemed successful. Unfortunately the second flight in July 2017 was unsuccessful and lost its payload after a first-stage failure. Two years after the failure, the China National Space Administration (CNSA) look to rejuvenate the rocket with its third launch, which could lead to the delivery of very exciting missions in the near future.

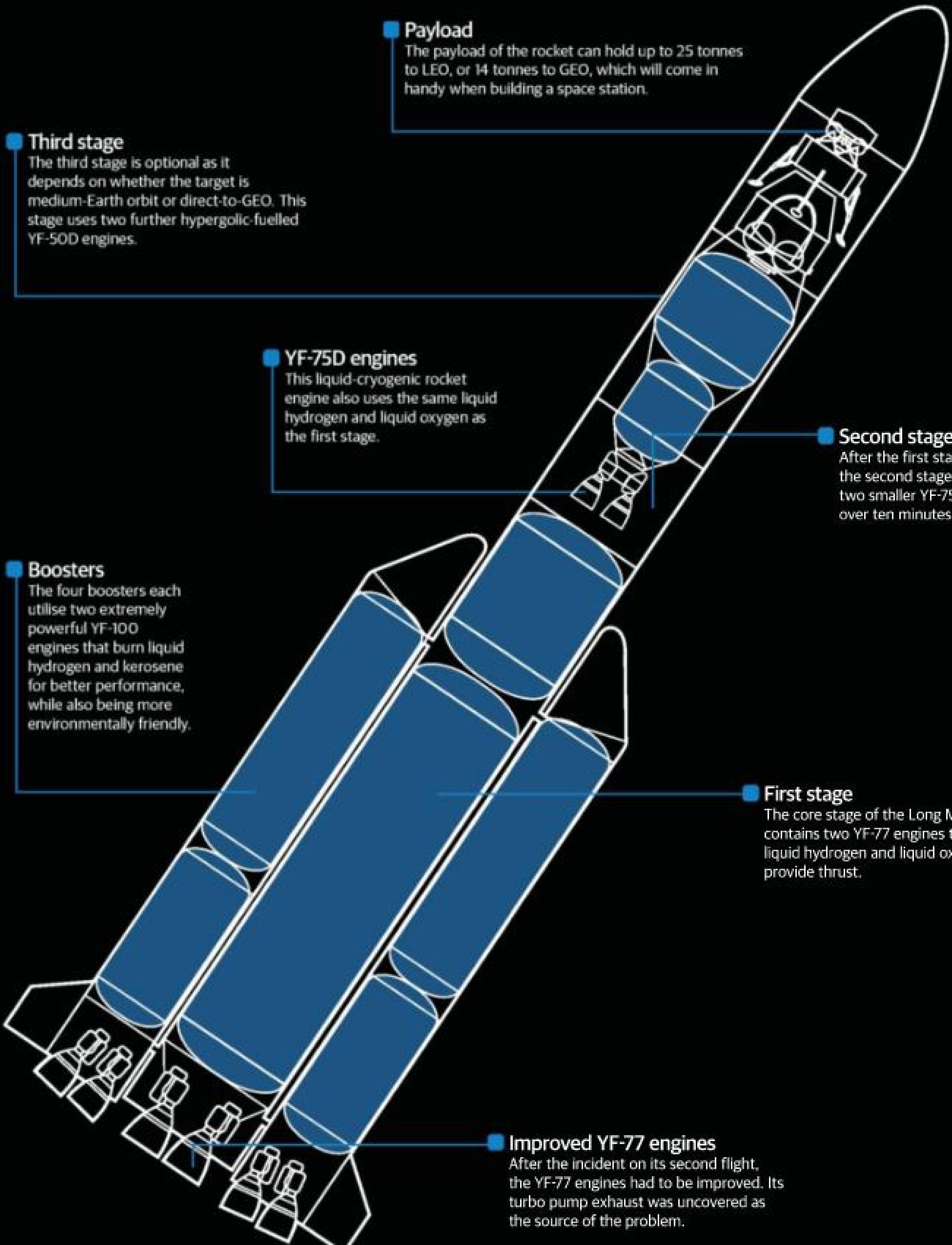
Before any plans can be divulged, however, the specifics of the rocket must be tested. It is a real testament to modern rocketry and could prove to be a heavyweight when it comes to launching space exploration missions. The fifth member of the Long March rocket family is the first Chinese vehicle designed from scratch that focuses purely on liquid rocket propellants. It is a two-stage - with the added potential of a third stage - heavy-lift rocket that utilises four boosters, each with two YF-100 engines, around a core stage that uses two YF-77 engines.

After the separation of the boosters the rocket will continue to fire two YF-77 engines in order to fly on to its trajectory. After roughly eight minutes of burn time, the second stage separates and uses two YF-75D engines that provide a further 176 kN

> "Since 2007 when funding began, the rocket has been constructed from the ground up"

Anatomy of a super rocket

China's most powerful booster consists of at least two stages and four boosters that will take it away from Earth and beyond



Payload
The payload of the rocket can hold up to 25 tonnes to LEO, or 14 tonnes to GEO, which will come in handy when building a space station.

Third stage
The third stage is optional as it depends on whether the target is medium-Earth orbit or direct-to-GEO. This stage uses two further hypergolic-fuelled YF-50D engines.

YF-75D engines
This liquid-cryogenic rocket engine also uses the same liquid hydrogen and liquid oxygen as the first stage.

Second stage
After the first stage separates, the second stage then uses two smaller YF-75D engines for over ten minutes of burn time.

Boosters
The four boosters each utilise two extremely powerful YF-100 engines that burn liquid hydrogen and kerosene for better performance, while also being more environmentally friendly.

First stage
The core stage of the Long March 5 contains two YF-77 engines that use liquid hydrogen and liquid oxygen to provide thrust.

Improved YF-77 engines
After the incident on its second flight, the YF-77 engines had to be improved. Its turbo pump exhaust was uncovered as the source of the problem.

© VCG / Getty; Adrian Mann

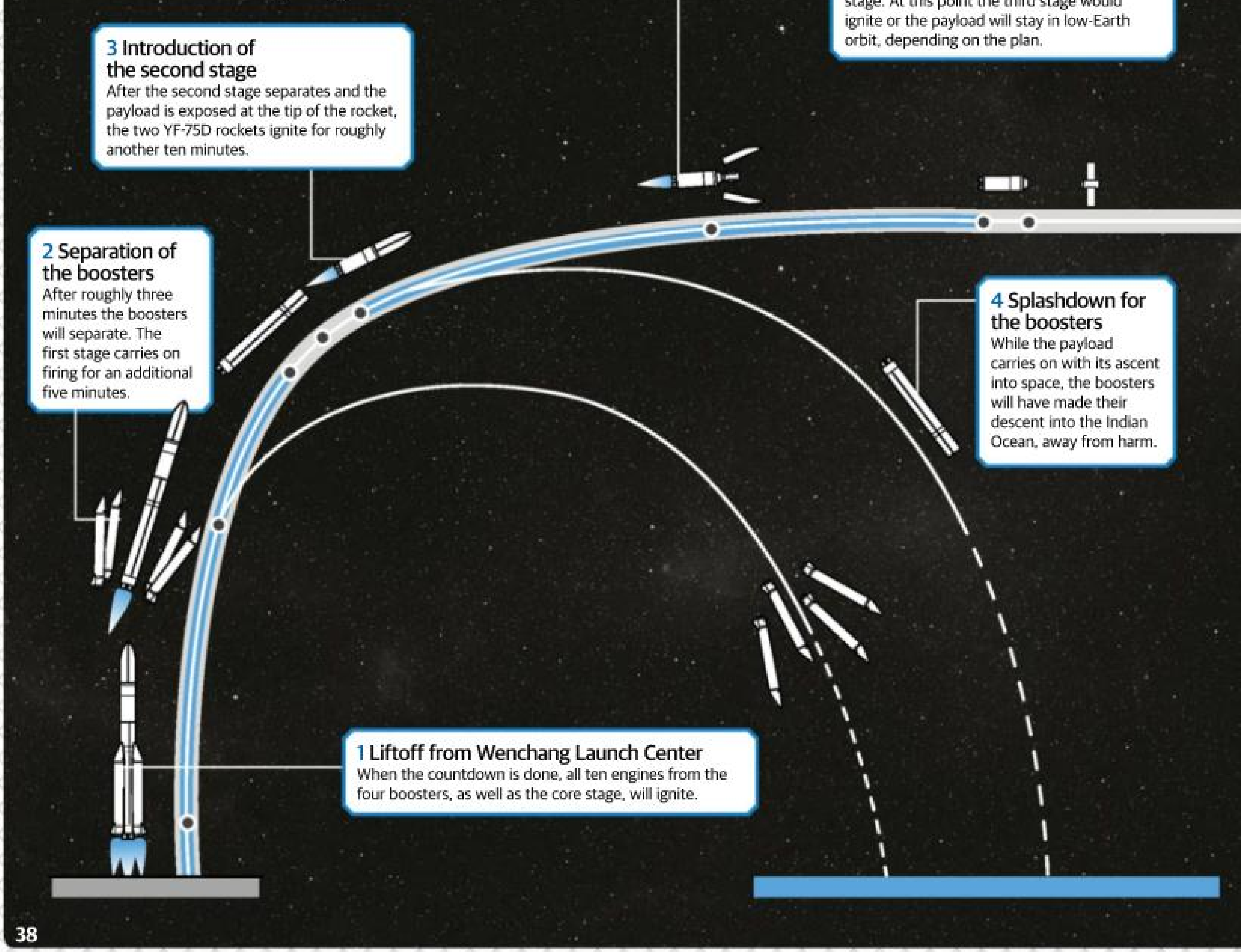
The Long March 5 launches from Wenchang Launch Center, Hainan Island

of thrust. Finally, if there is a third stage attached, which will help carry payloads beyond low-Earth orbit, the rocket will use its final two YF-50D engines to insert it onto a path that could be headed for the Moon or even beyond to Mars.

All this design and construction culminated in a maiden flight on 3 November 2016, when Long March 5 carried an experimental satellite called Shijan-17 from the Wenchang Launch Center on Hainan Island, just off the southern Chinese coast. Details of the launch weren't released immediately, but afterwards it was explained that the second stage encountered a slight issue that left the upper stage in an orbit slightly lower than expected. This was corrected by the boosters of the final stage.

The second mission came on 2 July 2017, where the Long March 5 was once again launched from Wenchang Launch Center, this time carrying the

How Long March 5 will launch its payload



1 Liftoff from Wenchang Launch Center
When the countdown is done, all ten engines from the four boosters, as well as the core stage, will ignite.

2 Separation of the boosters
After roughly three minutes the boosters will separate. The first stage carries on firing for an additional five minutes.

3 Introduction of the second stage
After the second stage separates and the payload is exposed at the tip of the rocket, the two YF-75D rockets ignite for roughly another ten minutes.

4 Splashdown for the boosters
While the payload carries on with its ascent into space, the boosters will have made their descent into the Indian Ocean, away from harm.

5 Payload separation
After the second stage's firing is complete, the payload will then separate from the second stage. At this point the third stage would ignite or the payload will stay in low-Earth orbit, depending on the plan.

Shijan-18 experimental communications satellite. Unfortunately this was deemed a failure as the satellite did not reach orbit. The issue appeared to begin after the initial four boosters separated. This led to the satellite failing to reach orbit, instead crashing into the Indian Ocean. This was later attributed to a turbo pump exhaust issue in one of the YF-77 engines that power the first stage.

The Chinese space agency has since taken its time in getting the next Long March 5 rocket into action. Its next launch is scheduled for July 2019, two years after the failure. Redemption in this case will involve launching from the same site on Hainan, carrying the Shijan-20 communications satellite. To prevent the same mishap, the rocket has redesigned YF-77 engines capable of withstanding the complex thermal conditions of launch. If launch is successful then it can begin carrying more exciting payloads such as the Chang'e-5 lunar sample-return mission, a Martian orbiter and rover and even begin delivering modules of the Chinese space station, Tiangong, which means 'Heavenly Palace' in Chinese.

CALT also has plans to improve on the Long March family with the introduction of the Long March 8 - a medium-life rocket that will notably be reusable after launch. However, main efforts at the moment are to focus on the Long March 5 and make sure its issues are in the past. There are many exciting missions and projects in the works that rely on this heavy-duty rocket being able to take payloads far away from Earth.

> "CALT also has plans to improve on the Long March family"

TOP TECH

The YF-100 engine

In the process of producing a more environmentally friendly engine that can provide the propulsion needed for heavy cargo delivery into space, the YF-100 engine was born. This is the most powerful engine used on the Long March 5 and is fitted twice over on each of the boosters, with each engine providing a thrust at sea level of 1,200 kN.

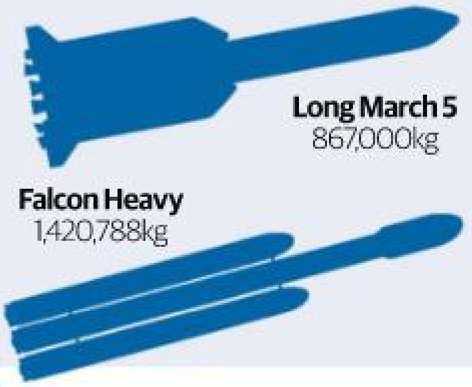
This engine is much more efficient and safer for the environment as CALT introduced cryogenic propulsion systems that use kerolox - a term used when burning both liquid oxygen and liquid kerosene - rocket fuel.

Head-to-head

Long March 5 vs Falcon Heavy

How does China's most powerful rocket compare to SpaceX's juggernaut? In terms of size, the Falcon Heavy is taller by 13 metres (43 feet), but Long March 5 has the wider diameter by just over a metre (three feet). However, the Falcon Heavy is reusable, with its two boosters and core stage able to land safely on intended landing zones. The Long March 5 takes the conventional rocketry approach of disposing of the boosters and first stage in the ocean.

Falcon Heavy does take the crown when it comes to most powerful rocket: it can take over 60 tonnes to LEO, as opposed to Long March 5's 25 tonnes.

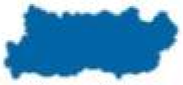


Vital statistics

57 metres = About 20 metres taller than the Christ the Redeemer statue

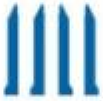
25 tonnes = The payload mass to LEO

5,840 kN = Thrust of Long March 5 on the ground



8.2 tonnes = The payload mass to send to the Moon

4 boosters = The most used by any rocket in the Long March family



FUTURE MISSIONS

Four missions that Long March 5 will carry into space

1 Chang'e-5

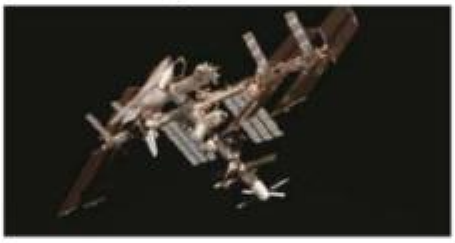
Its fourth edition made history as it became the first to explore the far side of the Moon, whereas Chang'e-5 could potentially collect a lunar surface sample and return it to Earth. This launch is currently scheduled for late 2019.

2 Mars Global Remote Sensing Orbiter and Small Rover (HX-1)

Mid-2020 could see the launch of a Martian explorer, consisting of a orbiter and a rover. The rover will be able to provide up-close analysis of the soil, searching for any signs of ancient life.

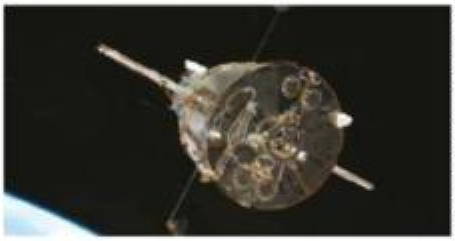
3 Tiangong program

Arguably the main reason to construct this heavy-duty rocket, the Tiangong program has seen two space laboratories launched in the past. With the Long March 5, a space station will be constructed starting in 2020.



4 Xuntian space telescope

Dubbed "more powerful than Hubble" the telescope could see space in the 2020s. This space telescope will follow the same orbit as the Chinese space station and will provide a field of view 300-times larger than Hubble's.



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The Space Race by Sarah Cruddas

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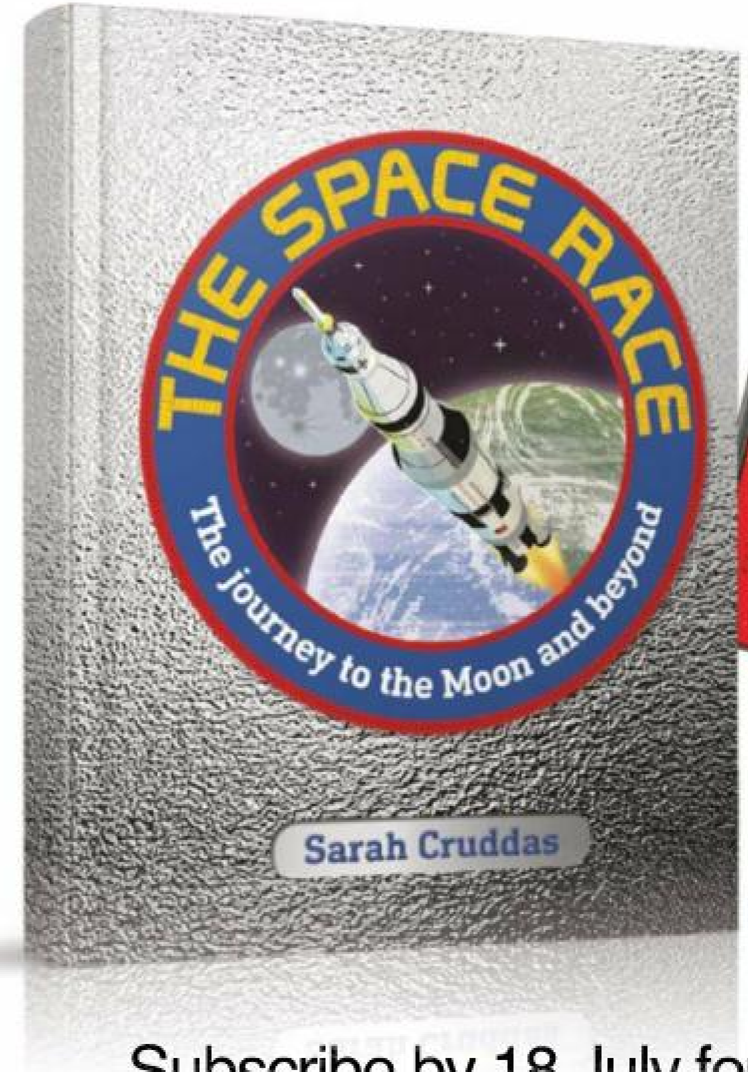

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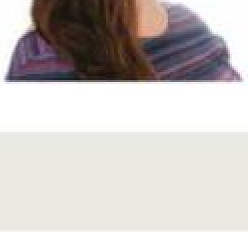

"*The Space Race* reveals all of the big questions about space travel. Author Sarah Cruddas brings to life the hidden stories behind the most famous space missions before taking the reader on a journey through the future of exploration of the cosmos.

"Propelled by recent scientific discoveries and printed to coincide with the 50th anniversary of the Apollo 11 Moon landing, *The Space Race* is essential to understanding every aspect of the history, and future and of human space travel."

Gemma Lavender, Editor-in-Chief

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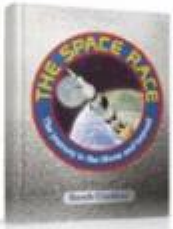

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Astronomers have unearthed exciting evidence for a Neptune-sized moon orbiting a Jupiter-sized planet 8,000 light years away

Reported by Lee Cavendish

FINDING THE FIRST EXOMOON

© dottedzebra / Alamy Stock Photo

> "Testing a hypothesis rigorously is part of science, and I'd be uncomfortable frankly if people simply took us at our word that this moon is real" **Alex Teachey**

Moons are found all throughout the Solar System. In fact, there are 184 known moons orbiting the 13 planets and dwarf planets, with just over 70 per cent of them orbiting the two gas giants, Jupiter and Saturn. If you apply the same figures to the latest known exoplanet count – 3,972 at the time of writing – for a rough estimate, there could be a potential number of at least 55,000 moons outside our Solar System, also known as exomoons. This is a staggering number, but it also raises a question: why hasn't an exomoon been discovered yet?

Discoveries regarding exoplanets have been at the forefront of astronomy for the last two decades and have produced some of the most headline-generating space news of recent times. But another recent piece of news has generated equally exciting headlines, as astronomers claim to have made the first-ever detection of an exomoon. Two astronomers at Columbia University in New York have found the first possible beacon signal for an exomoon around exoplanet Kepler-1625b, about 8,000 light years away from Earth. In 2017, Alex Teachey and Dr David Kipping, astronomers at Columbia, went through 284 exoplanet candidates discovered by NASA's now-deceased Kepler space telescope before they found a possible detection of a moon around Kepler-1625b. **All About Space** spoke to Teachey at the time: "We seem to have a pretty good idea of what this moon would look like, and what that allows us to do is then project into the future. We now have some sort of prediction as to what we're looking for in the October [2017] transits. If we find a good fit this would be really strong evidence that we've made a successful prediction. But at this point it's tough because there are so few transits. So we're approaching with an abundance of caution. Until we observe it with Hubble, we're just not going to be entirely convinced."

Now, two years after that interview, Teachey and Kipping have found even more evidence that the exomoon, named Kepler-1625b-i, exists. They had their time with Hubble, and the results look promising. "Since that first paper came out there have been a range of reactions, from excited to skeptical, and that's all to be expected. Testing a hypothesis rigorously is part of science, and I'd be uncomfortable frankly if people simply took us at our word that this moon is real," Teachey divulges to **All About Space**. "As the famous saying goes, 'extraordinary claims require extraordinary evidence'. I think this certainly counts as an extraordinary claim, but we've tried to be up front about the fact that, right now anyway, we haven't got extraordinary evidence. We've got 'evidence'."

The evidence in this case is hidden in the light of the host star. The same technique that has been so successful in confirming the existence of thousands of exoplanets is also being used to find exomoons, but it is a much more difficult challenge. When astronomers talk about 'transits', they are talking about when an object moves in front of its host star from the perspective of Earth, and blocks a part of the star's light. By measuring the star's brightness over a period of time in what's known as a 'light curve', astronomers can watch the transit of the object moving in front of the star, thus determining its existence. In this instance Teachey and Kipping observed the transit of exoplanet Kepler-1625b, but in 2017 also saw a much smaller transit that could be the calling card of the first-ever moon found outside the Solar System.

If the evidence and analysis are correct then the exomoon is close to the size of Neptune and orbits a planet three-times the size of Jupiter, both of which orbit a star similar to the Sun in a close orbit. The size difference between Kepler-1625b and its moon is comparable to the Earth and Moon system. The anomalies in Kepler-1625's transits are what brought the exomoon hypothesis to the world's attention. "The first [anomaly] is that the planet appears to transit

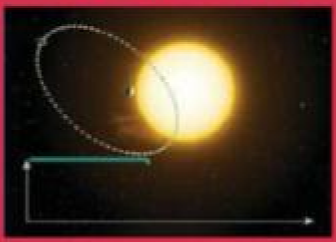
Right: Kepler's successor, TESS, has continued the search for habitable planets outside our Solar System

Left: Hot Jupiters are easier to detect because of their relatively large size and short orbit duration

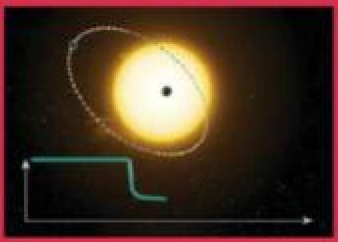
Below: The Kepler-1625b system, consisting of a Neptune-sized moon orbiting a Jupiter-sized world

How did astronomers discover the exomoon?

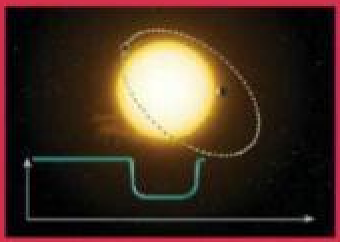
Using data from the Hubble Space Telescope and Kepler space telescope, astronomers were able to catch the starlight's signal of Kepler-1625b-i



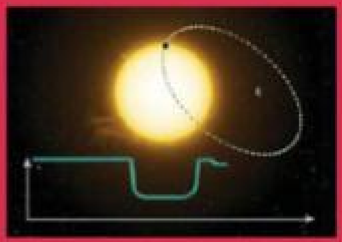
Kepler-1625b emerges
The exoplanet Kepler-1625b begins to block out light as it crosses in front of the star's face, but the moon is not doing the same.



Observing the starlight
As Kepler-1625b continues on its orbit the star loses a fraction of its brightness halfway through the transit, equating to about 9.5 hours.



The end of exoplanet transit
The Hubble Space Telescope observed close to the full 19-hour-long transit. However, the moon was just about to enter the frame.



Kepler-1625b-i appears
Three-and-a-half hours after Kepler-1625b's transit, a second smaller transit was observed, attributed to the exomoon Kepler-1625b-i.

© NASA, ESA, Nicholas Foeder, Tobias Roetsch

How are moons made?

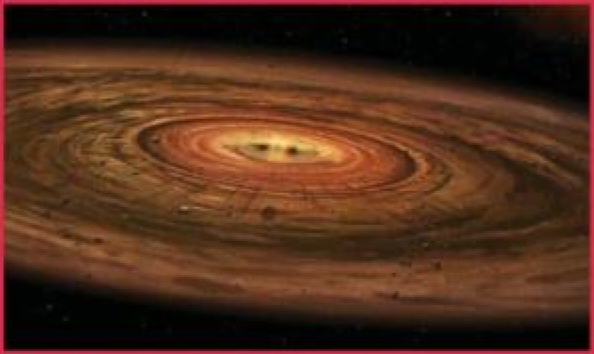
Satellites can form in different ways, as seen throughout the Solar System

The giant-impact scenario

This scenario also depicts how the Earth got its Moon. When a planetary system is in its early years of formation, there are planets, planetesimals and large chunks of debris constantly colliding. If a planet is struck by an extremely large object, chunks of material come flying off and gravity brings them together to form a moon.

The gravity-capture scenario

Large planets like the gas giants Jupiter, Saturn, Uranus and Neptune have extremely powerful gravitational attraction. If an object gets too close, the planet will not let it leave its grasp. So when a large dwarf planet-sized object flies too close to a large planet, it will be captured and forms a moon. This is how Neptune got its moon Triton.



Moon-accretion scenario

Similar to how all objects formed around the Sun at its epoch, moons could have formed from a disc of material orbiting extremely large planets. Jupiter's famous Galilean moons – Io, Ganymede, Europa and Callisto – supposedly formed in this manner by the accretion of leftover orbiting debris.

© NASA/JPL-Caltech; Nicholas Forder;

one-and-a-quarter hours too early; that's indicative of something gravitationally tugging on the planet," Kipping says. "The second anomaly is an additional decrease in the star's brightness after the planetary transit has completed."

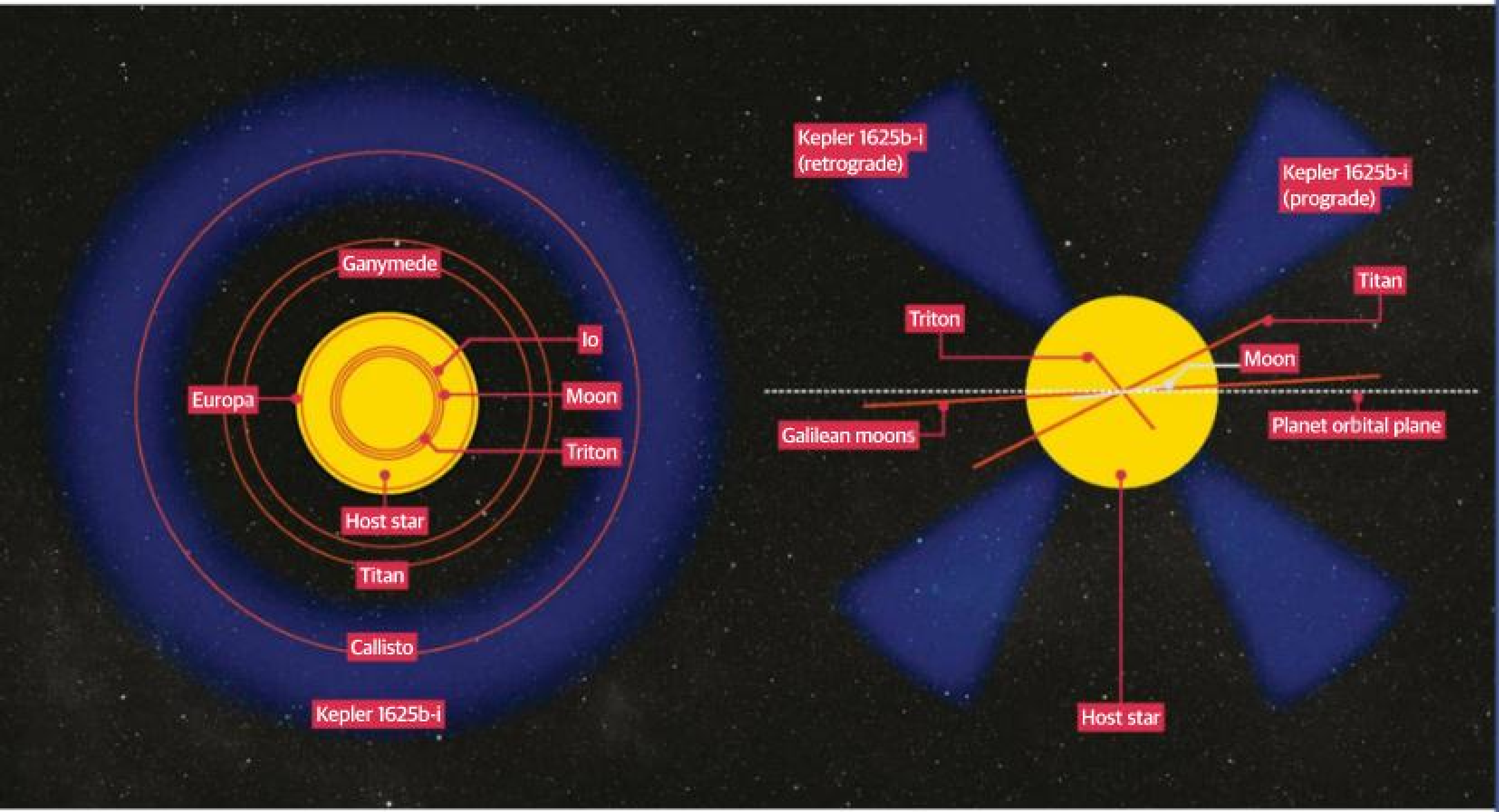
This analysis has not come without skepticism, and doubt is cast over the processing of the data. Independent researchers including Laura Kreidberg of the Harvard-Smithsonian Center for Astrophysics in Massachusetts and René Heller of the Max Planck Institute for Solar System Research in Germany have re-examined the data. After inspection, they have both stated that the exomoon candidate was likely either an artefact of the data processing or simply that there is not enough data to make such a bold claim. In response to these claims, Teachey argues: "The fact is that after their own careful, independent analysis, making their own decisions, they saw the same feature we did in the data, and they haven't got any explanation for what it is if it's not astrophysical in nature.

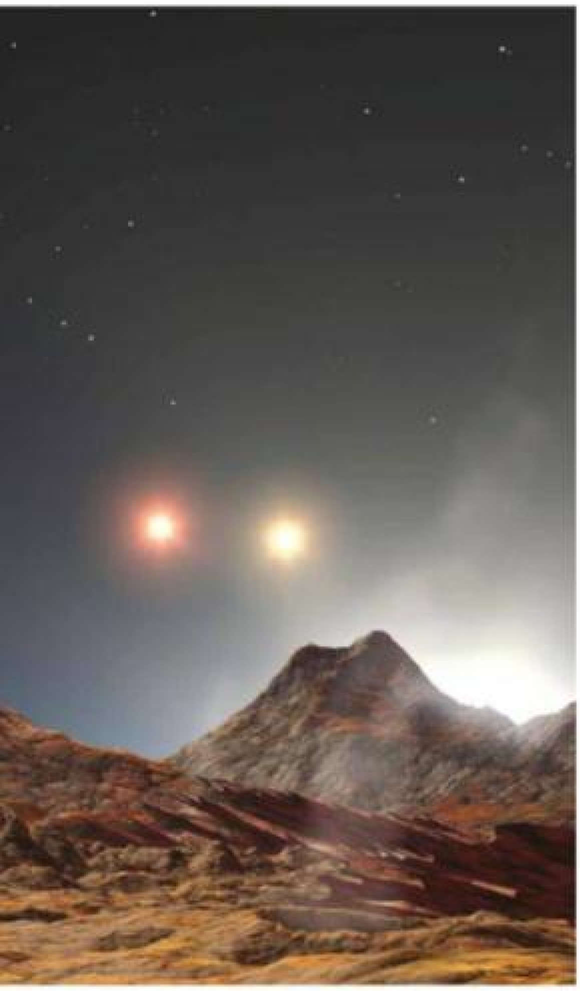
"What's left? Continued monitoring of the transit times, which you can do with more modest telescopes, would be valuable for characterising the system. Right now we only have four transits to work with, but adding more would fill out the picture a bit more." That's the only way that this candidate can be solidified as the first-ever exomoon detection – more and more data.

As well as light curves, Teachey and Kipping would also like radial velocity measurements,

Right: A top-down and side-on view of how Kepler 1625b-i compares to the orbits of Jupiter's moons

Below: Exoplanets and exomoons could hold exotic discoveries for the future





> "The second anomaly is an additional decrease in the star's brightness after the planetary transit has completed" **David Kipping**

studying the gravitational wobble exerted on the host star by Kepler-1625b and its moon via the art of spectroscopy. This would help define the physical characteristics of the system while identifying if there is another planet in the system. "We hope to re-observe the star again in the future to verify or reject the exomoon hypothesis," Kipping explains. "If validated, the planet-moon system - a Jupiter with a Neptune-sized moon - would be a remarkable system with unanticipated properties, in many ways echoing the unexpected discovery of hot Jupiters in the early days of planet hunting."

But it's one thing discovering an exomoon, and another thing understanding it. If its physical dimensions are proven to be true, then astronomers could soon be scratching their heads wondering how a Neptune-sized satellite originates. In fact, they have already begun. There are currently three ways astronomers believe a moon can come to be. The one we are most familiar with is the way our Moon formed, or the giant-impact scenario. In the early ages of a planetary system a huge object collides with an even bigger object, and leftover debris from the collision congregates to form a moon. In another scenario, a moon is captured by the gravity of a planet. Neptune's moon Triton wandered away from the Kuiper Belt to be seized by the most outward planet in this way. There is also the theory that moons can accrete from a disc of material encompassing a large planet, similar to how the planets formed around the Sun and how the Galilean moons formed around Jupiter.

"Of these, I think it's safe to say that the accretion scenario cannot be responsible for making a moon like this; it's just too massive," says Teachey. "I'd say it's likely the gravity-capture scenario or maybe the giant-impact scenario. And the inclination of the moon I would say is sort of circumstantial evidence in support of these scenarios. Triton, too, is significantly inclined with respect to Neptune's orbit, but this doesn't necessarily point towards a capture scenario because we have no information about the axial tilt of the planet."

If the system does turn out to be a Neptune-sized moon around a hot Jupiter then the assumption can be made that they are two gas giants, and impacts between two gas giants haven't been heavily studied. For this reason the giant-impact scenario is a huge maybe. A gas giant moon would broaden horizons for all astronomers as it goes against the idea that moons have to be relatively small pieces of rock or ice, instead revealing moons could be a world almost four-times the diameter of Earth with the potential to be made largely of gas.

Recent years have seen a lot of attention turn to the moons of the Solar System. No longer are they thought of as simple balls of rock and ice that are merely leftover debris from the formation of the Solar System - they are now considered gold mines for exciting scientific research in all areas of astronomy, biology and chemistry. Many astronomers even believe that some moons in the Solar System could be the best places to look for life outside of Earth. "There are interesting places in our own Solar System, such as Europa, Enceladus, Titan and other places that are very intriguing, and could even be habitable," says Teachey. "If similar moons turn out to be habitable in other parts of the galaxy, then this expands the number of places where life could arise." If you extrapolate our knowledge of exciting moons in our local system to the number of known planetary systems elsewhere in the galaxy, the chance of alien life becomes scarily stimulating.

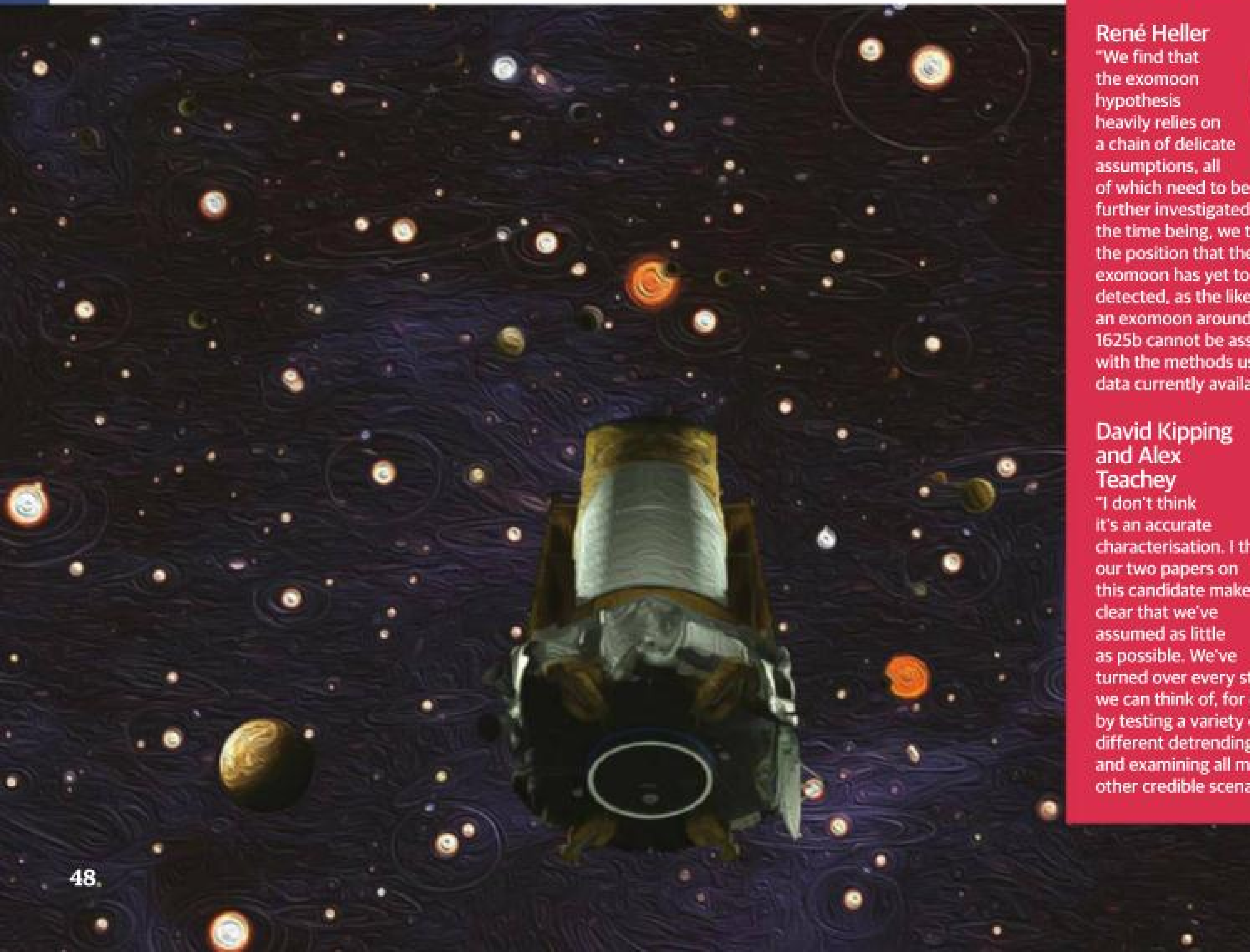
Although this is an area of astronomy that can prove a huge challenge for a few reasons, it can equally provide huge discoveries to the scientific community. Exoplanetary research is a topic that many astronomers are studying, but exomoons are just a fraction of that. We asked Teachey why this is the case: "Chiefly, it's very difficult. The data we have now from Kepler and TESS - as fantastic as they are - just isn't sensitive enough in general to find the kind of moons we expect to see, so it's rare to find a system that's got everything working in our favour."

It's no mere coincidence that the majority of exoplanets being discovered and confirmed are planets much larger than the Earth orbiting close to their host stars, because they are blocking an obvious amount of light in durations of days instead of years. It is a much more difficult task in deducing moons, a tiny transit in front of a star in a period that is not only dependant on its host's orbit around the star, but the orbit around the exoplanet as well.

Teachey is confident, however, that this is an exciting field of research, and he encourages more astronomers to join the hunt for unseen moons beyond the Solar System, which is set to only increase in momentum and popularity for many more inspiring discoveries to come.

> "If similar moons turn out to be habitable, then this expands the number of places where life could arise" **Alex Teachey**

Below: The now-retired Kepler space telescope discovered thousands of exoplanet candidates



© NASA; Dan Durda

What the exomoon hunters are saying

Laura Kreidberg

"I have been working on data analysis for this particular instrument on Hubble for about seven years now, so my pipeline has been put through the wringer. Even the hint of a signal that they saw doesn't hold up in the new analysis. [We] conclude that the lunar transit signal found was likely an artefact of the data reduction."

David Kipping and Alex Teachey

"Suffice to say, we think the picture is a bit more complicated than is being reported. That is, newer studies are not right by virtue of being new, and I think reporting along the lines of 'the moon isn't there after all' would be a bridge too far given the evidence in hand."

René Heller

"We find that the exomoon hypothesis heavily relies on a chain of delicate assumptions, all of which need to be further investigated. For the time being, we take the position that the first exomoon has yet to be detected, as the likelihood of an exomoon around Kepler-1625b cannot be assessed with the methods used and data currently available."

David Kipping and Alex Teachey

"I don't think it's an accurate characterisation. I think our two papers on this candidate make clear that we've assumed as little as possible. We've turned over every stone we can think of, for example by testing a variety of different detrending methods and examining all manner of other credible scenarios."

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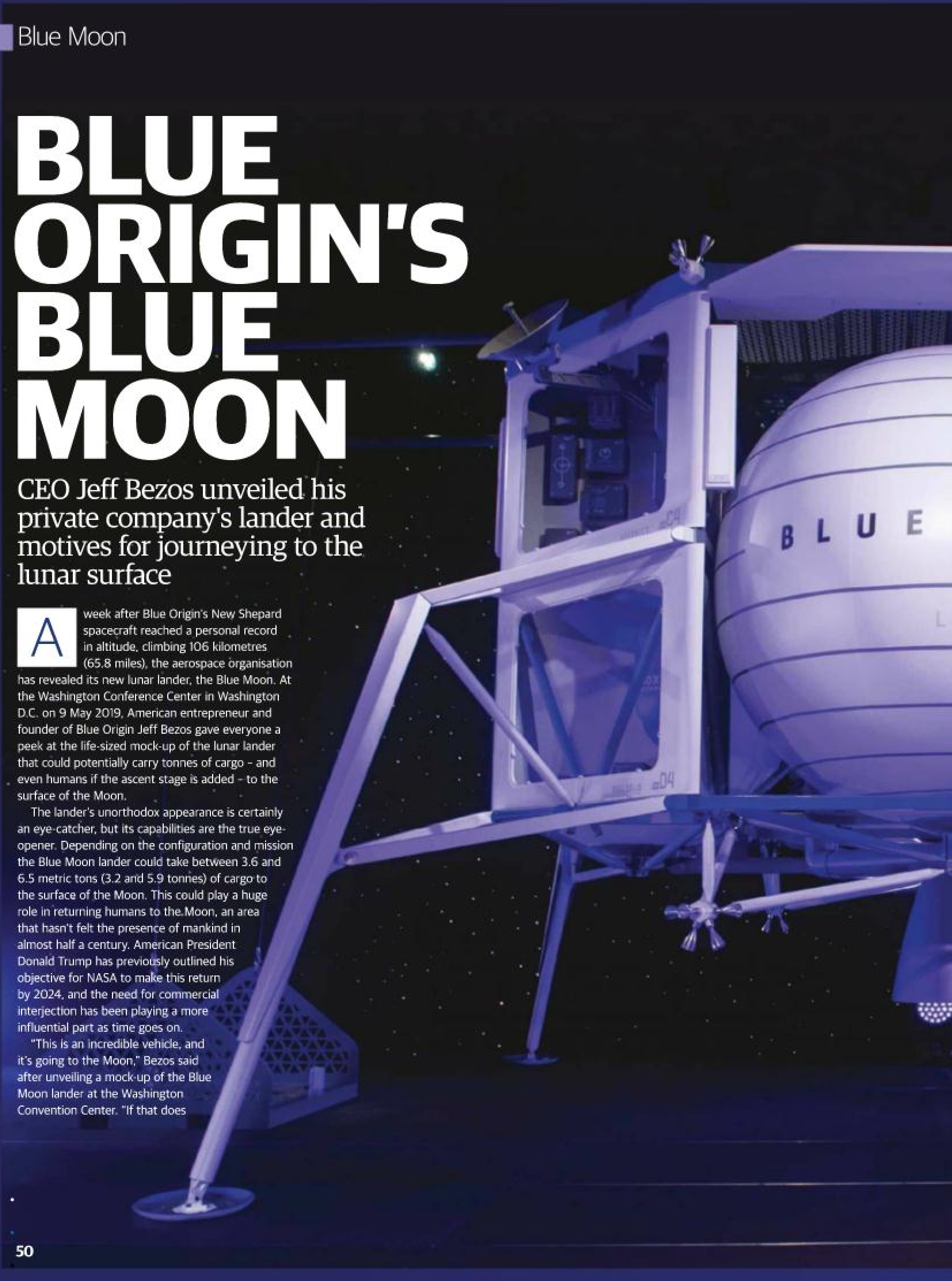
BLUE ORIGIN'S BLUE MOON

CEO Jeff Bezos unveiled his private company's lander and motives for journeying to the lunar surface

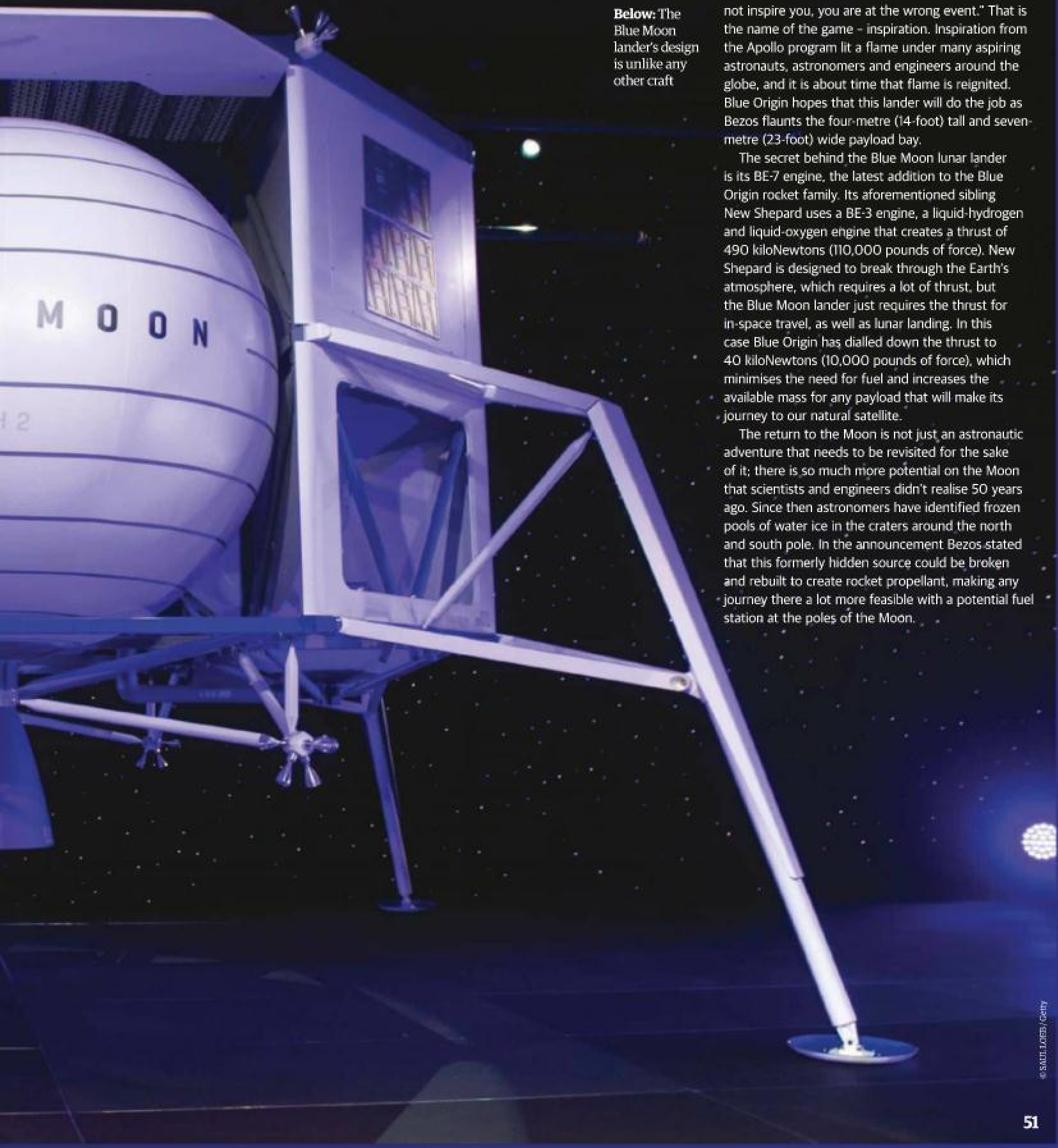


A week after Blue Origin's New Shepard spacecraft reached a personal record in altitude, climbing 106 kilometres (65.8 miles), the aerospace organisation has revealed its new lunar lander, the Blue Moon. At the Washington Conference Center in Washington D.C. on 9 May 2019, American entrepreneur and founder of Blue Origin Jeff Bezos gave everyone a peek at the life-sized mock-up of the lunar lander that could potentially carry tonnes of cargo – and even humans if the ascent stage is added – to the surface of the Moon.

The lander's unorthodox appearance is certainly an eye-catcher, but its capabilities are the true eye-opener. Depending on the configuration and mission the Blue Moon lander could take between 3.6 and 6.5 metric tons (3.2 and 5.9 tonnes) of cargo to the surface of the Moon. This could play a huge role in returning humans to the Moon, an area that hasn't felt the presence of mankind in almost half a century. American President Donald Trump has previously outlined his objective for NASA to make this return by 2024, and the need for commercial interjection has been playing a more influential part as time goes on.

"This is an incredible vehicle, and it's going to the Moon," Bezos said after unveiling a mock-up of the Blue Moon lander at the Washington Convention Center. "If that does

> “This is an incredible vehicle, and it’s going to the Moon” **Jeff Bezos**



Below: The Blue Moon lander’s design is unlike any other craft

not inspire you, you are at the wrong event.” That is the name of the game – inspiration. Inspiration from the Apollo program lit a flame under many aspiring astronauts, astronomers and engineers around the globe, and it is about time that flame is reignited. Blue Origin hopes that this lander will do the job as Bezos flaunts the four-metre (14-foot) tall and seven-metre (23-foot) wide payload bay.

The secret behind the Blue Moon lunar lander is its BE-7 engine, the latest addition to the Blue Origin rocket family. Its aforementioned sibling New Shepard uses a BE-3 engine, a liquid-hydrogen and liquid-oxygen engine that creates a thrust of 490 kiloNewtons (110,000 pounds of force). New Shepard is designed to break through the Earth’s atmosphere, which requires a lot of thrust, but the Blue Moon lander just requires the thrust for in-space travel, as well as lunar landing. In this case Blue Origin has dialled down the thrust to 40 kiloNewtons (10,000 pounds of force), which minimises the need for fuel and increases the available mass for any payload that will make its journey to our natural satellite.

The return to the Moon is not just an astronautic adventure that needs to be revisited for the sake of it; there is so much more potential on the Moon that scientists and engineers didn’t realise 50 years ago. Since then astronomers have identified frozen pools of water ice in the craters around the north and south pole. In the announcement Bezos stated that this formerly hidden source could be broken and rebuilt to create rocket propellant, making any journey there a lot more feasible with a potential fuel station at the poles of the Moon.

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Seismic waves unleashed by the violent forces inside stars are revealing some once-hidden secrets of stellar interiors

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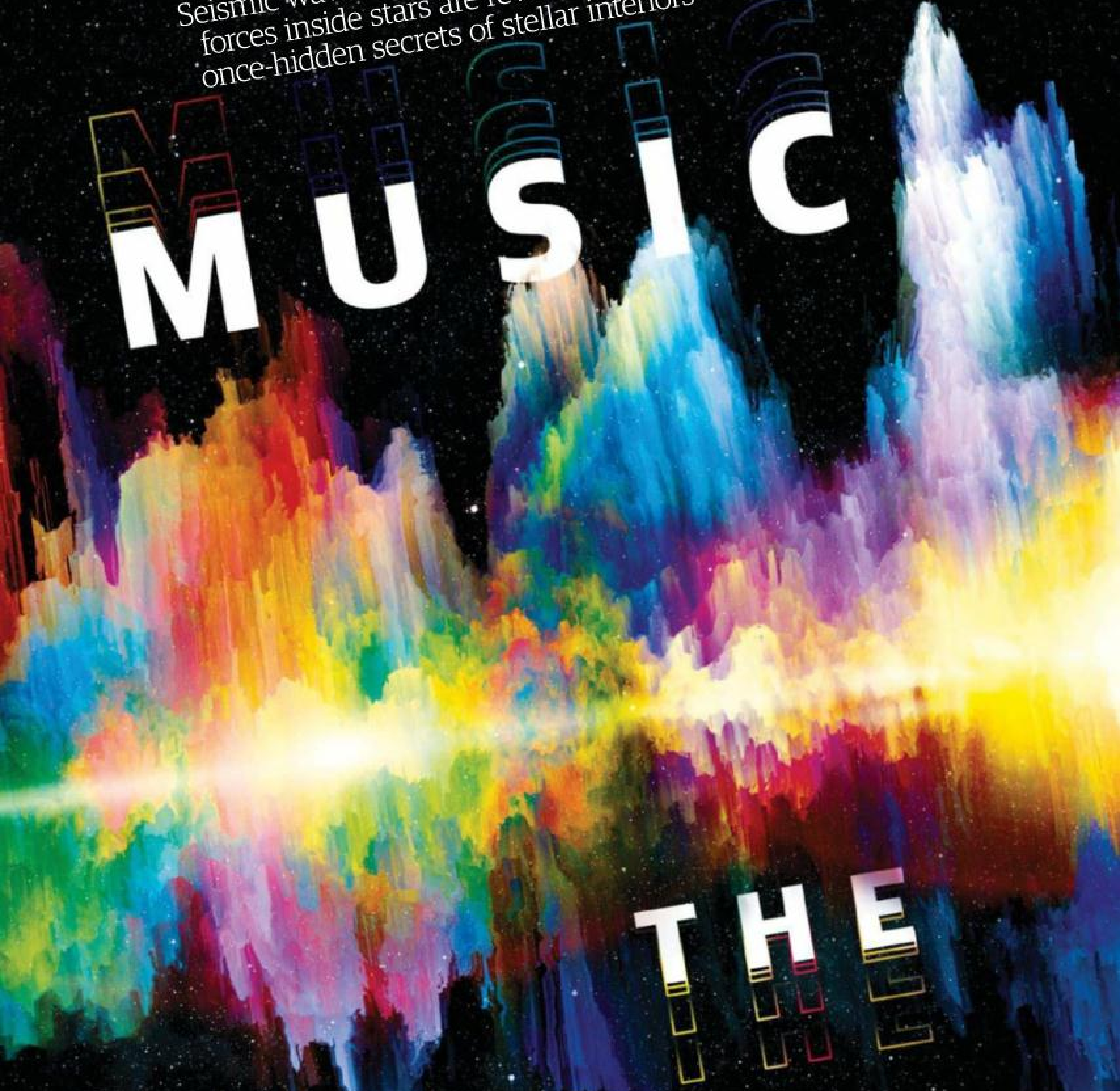

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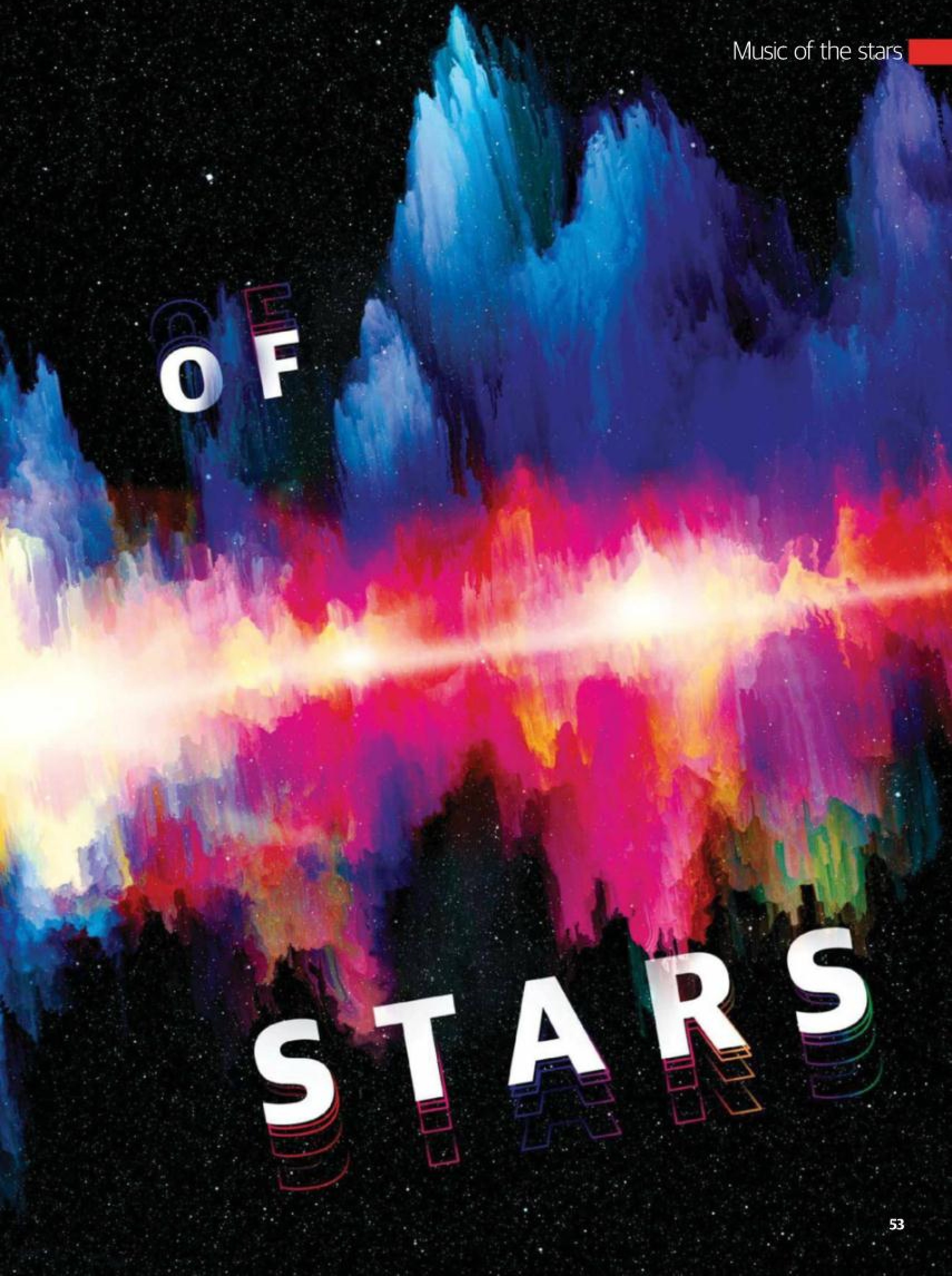


OF

STARS

KEPLER
by the numbers

9.6
YEARS IN SPACE

2 MISSIONS COMPLETED

2,662
PLANETS CONFIRMED ✓

530,506
STARS OBSERVED

61
SUPERNOVAE DOCUMENTED

3.12
GALLONS OF FUEL USED

732,128
COMMANDS EXECUTED

678GB
SCIENCE DATA COLLECTED

What does a star sound like? It might seem like a strange question, but every star in the sky is generating sound waves, even if we can't hear them across light years of vacuum. What's more, these stellar waves have frequencies much too low for human hearing - periods of minutes to hours compared to the 20 to 20,000 cycles per second our ears can pick up.

In effect, these soundwaves are the same as the seismic waves that cause earthquakes on our own planet - most earthquakes are triggered in Earth's relatively thin outer crust, and similarly stellar seismic waves are generated by the churning of huge masses of gas in the upper layers close to a star's visible surface. But both types of wave ripple out in all directions, passing all the way through both planet and star. So just as geologists can use seismic waves to probe Earth's inner structure, so astronomers are now finding that the sound waves of stars can reveal their secrets.

Professor Tim Bedding is part of a team at the University of Sydney that uses this new technique, known as asteroseismology, to study the later stages of stellar evolution. "A star is a huge ball of gas held together by its own gravity," he explains, "and many stars undergo oscillations that involve periodical expansion and contraction. By measuring the periods of these oscillations we can infer conditions deep inside the star, such as temperature and chemical composition."

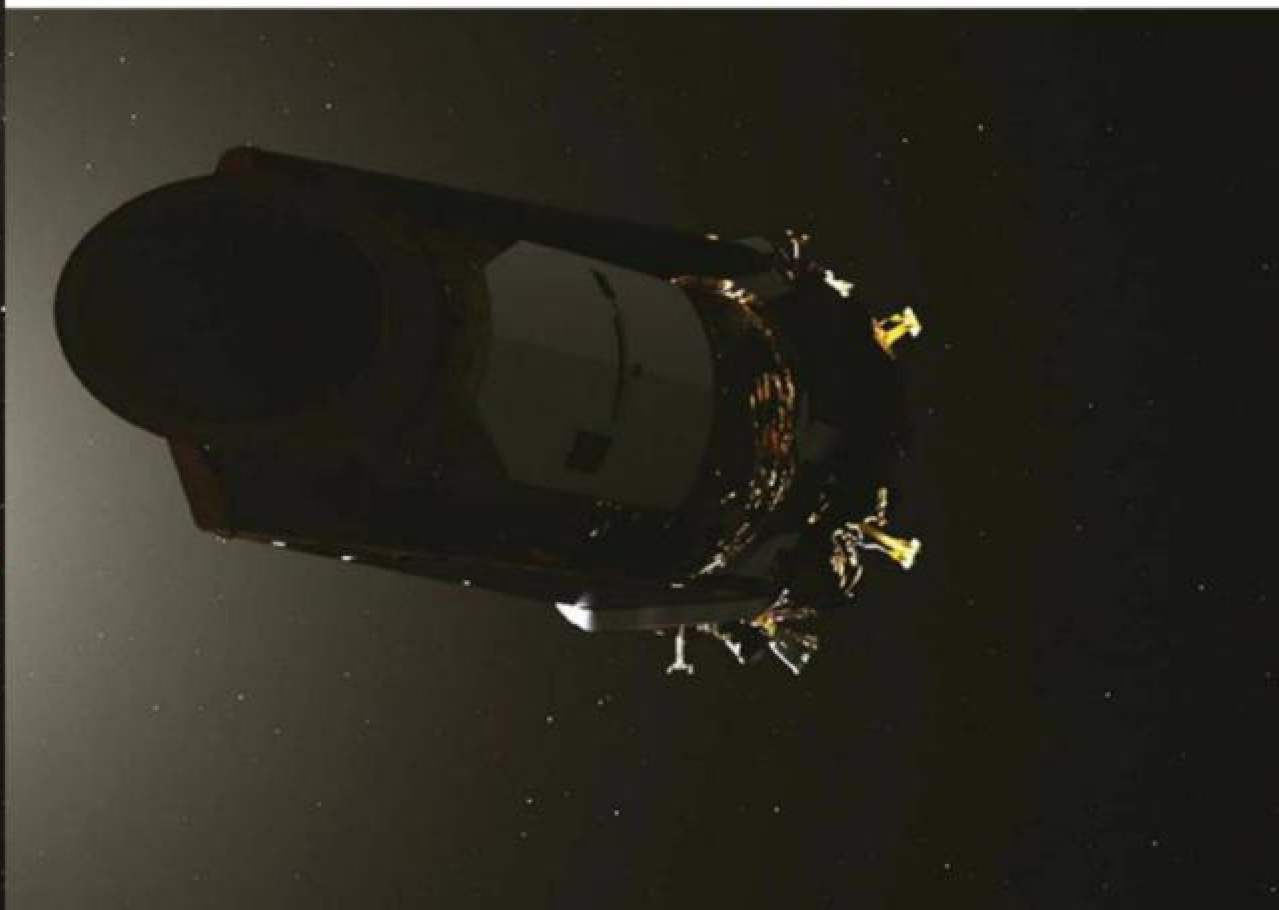
So how do the waves manifest themselves? "They're rather like the oscillations inside the tube of a flute or trumpet," continues Bedding, "except that a star is three dimensional, which makes its oscillations more complicated." In a wind instrument, waves are limited to oscillating in just one dimension, rippling back and forth and settling into stable patterns known as modes. "But while an instrument has a limited number of modes, a star like the Sun can oscillate in hundreds or even thousands of different modes simultaneously."

But there's a problem - while the Sun is on our cosmic doorstep and has been studied in detail by 'helioseismologists' since the 1970s, other stars are many millions of times more distant - mere points of light through even the most powerful telescopes. Directly observing ripples on their surfaces is far beyond current technology, but fortunately, as Professor Bedding points out, the waves also produce an effect we can measure: "They affect the light output of the star, causing its brightness to vary in time by small amounts in a very complicated way."

That's the theory at least, but putting it into practice is another matter: "Measuring those brightness variations from the ground is very difficult due to the effects of the Earth's atmosphere. What we really need is a space telescope that can make regular and very accurate measurements of stellar brightness."

Fortunately, in 2009 NASA launched a satellite that provides just this kind of data. The Kepler

> "They're rather like the oscillations inside the tube of a flute or trumpet, except that a star is three dimensional" **Prof Tim Bedding**



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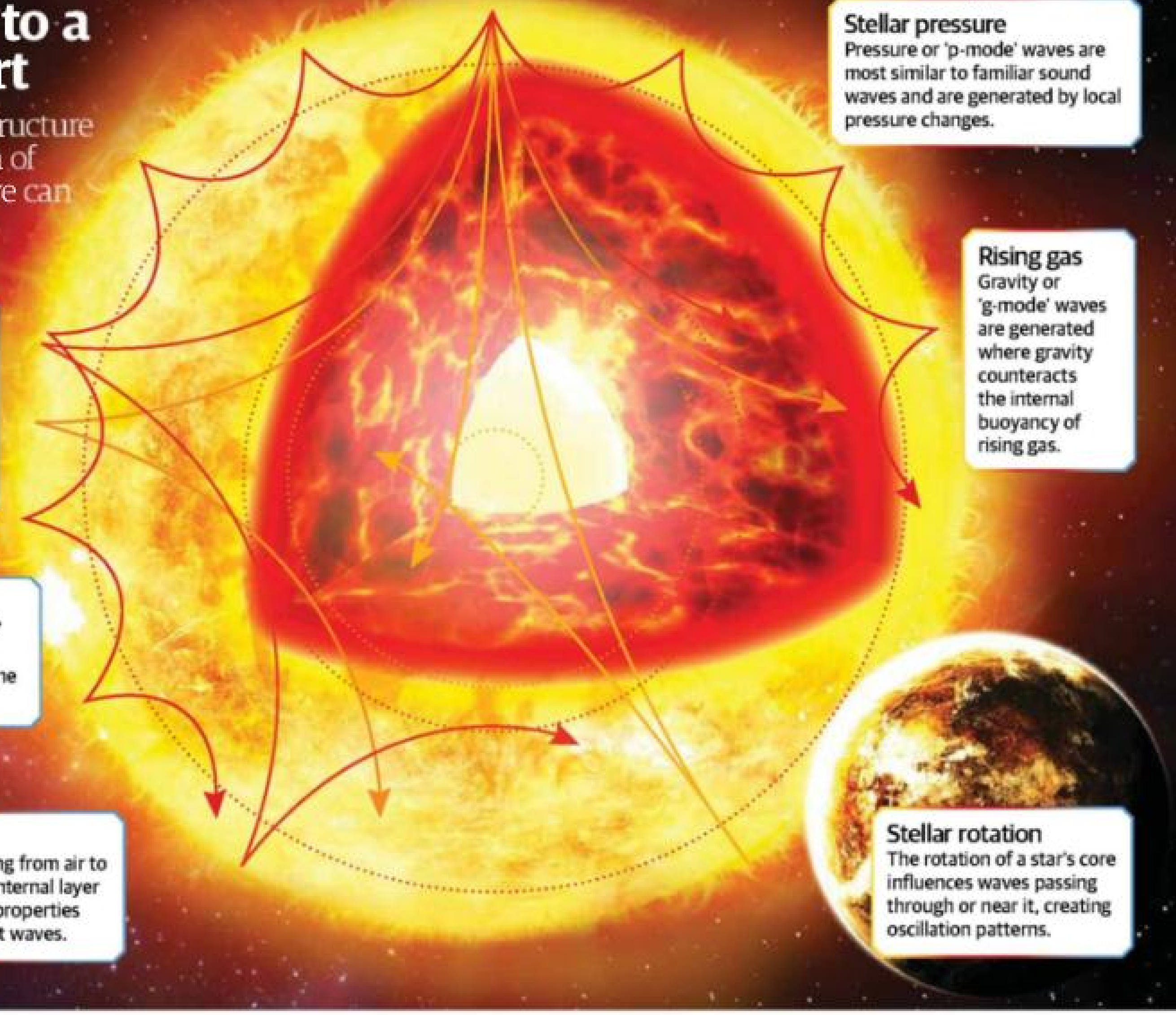
Listening to a star's heart

A star's internal structure affects the pattern of oscillations that we can see at its surface



Stellar pressure
Pressure or 'p-mode' waves are most similar to familiar sound waves and are generated by local pressure changes.

Rising gas
Gravity or 'g-mode' waves are generated where gravity counteracts the internal buoyancy of rising gas.

Into the core
The speed which waves travel through the core reveals its composition and likely age – waves move faster through higher density materials like helium.

Stellar ripples
Surface-gravity or 'f-mode' waves are created at the surface and move across the star like ocean waves.

Star layers
Just like light waves passing from air to water, passage from one internal layer to another with different properties can deflect, or even reflect waves.

Stellar rotation
The rotation of a star's core influences waves passing through or near it, creating oscillation patterns.

Far left: Kepler's main aim was to detect exoplants orbiting around far-off stars

Left: Stars further than the Sun appear as points of light in even the most advanced telescopes, making up-close observations difficult

mission's main aim was to detect planets around distant stars by measuring the tiny regular dips in their brightness when a planet transits across the face of the star. But its highly accurate measurements are also perfect for asteroseismology. "It's created a revolution in the field over the past few years," enthuses Bedding.

By identifying the complex interacting wave modes influencing a star's brightness and comparing them to computer models of stellar interiors, it's possible to work out the arrangement of layers with different densities inside the star. Perhaps the best example so far comes from the Sydney team's recent work on red giants - stars near the end of their lives that have swollen to enormous size as they start to run out of fuel.

Stars like the Sun shine by nuclear fusion of hydrogen into helium in their cores. But after a few billion years the core hydrogen is fully converted to helium, and the star starts burning the hydrogen in a shell around the core.

Bedding takes up the story: "When this happens, the outer part of the star expands and cools, creating a red giant. But at the same time, the helium core contracts and gets hotter. Eventually it's hot enough for helium to start fusing into carbon

Stellar concert

Thanks to observations from Kepler, amongst other missions, it's now becoming clear that all stars have their own regular oscillations - like instruments in an orchestra

Sunlike subgiant

Mass: 1.2 solar masses
Radius: 2.1 solar radii
Temperature: 5,500°C (9,932 °F)

High density star
KIC 11026764 has just begun the journey to become a red giant. Its relatively high density produces high-frequency seismic waves.

Shell burning
Deep inside the star lies a burnt-out core of helium surrounded by a hydrogen-burning shell that generates energy.

Small red giant

Mass: 1 solar mass
Radius: 5 solar radii
Temperature: 5,000 °C (9,032 °F)

Small giants
Comparatively small red giants generate relatively high-frequency waves - though still much lower than those of subgiants.

Weak waves
The waves in small red giants are also comparatively weak, with small amplitudes.

Large red giant

Mass: Around 1 solar mass
Radius: 20 solar radii
Temperature: 4,000°C (7,232 °F)

Bigger and cooler
As a red giant brightens and swells in size, its surface cools because there is a far larger surface area for energy to escape through.

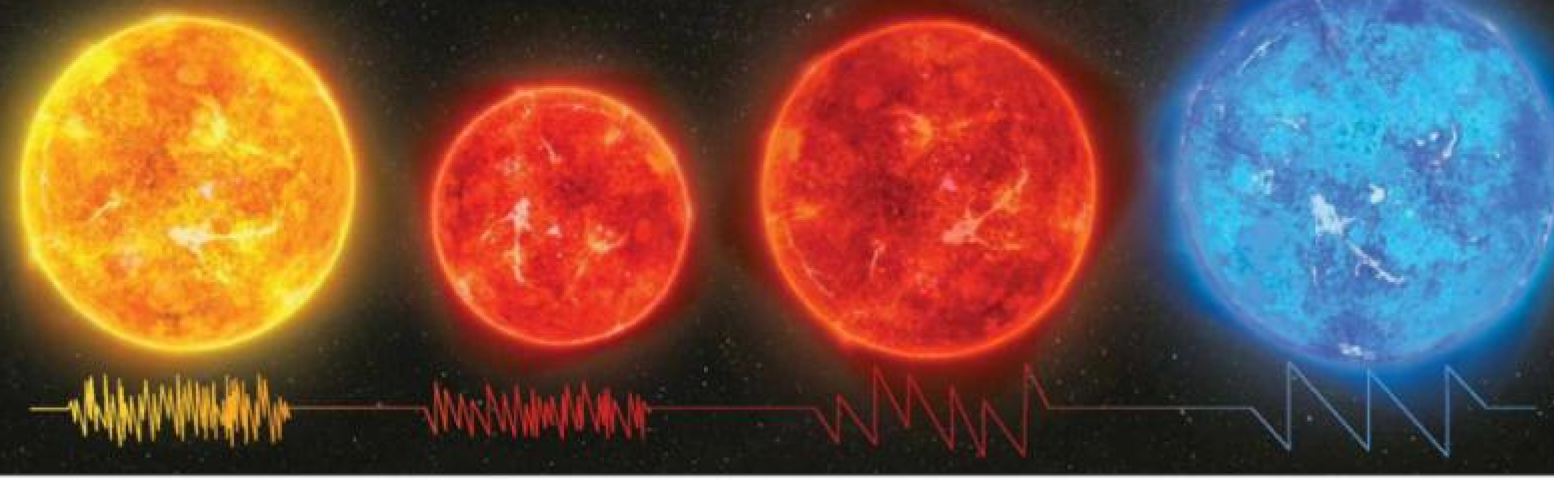
Slower and stronger
Seismic waves in bigger red giants are more powerful, but have lower frequencies as they move more slowly in the low-density stellar interior.

RR Lyrae star

Mass: 0.65 solar masses
Radius: 5 solar radii
Temperature: 6,000°C (10,832 °F)

Strange giant
RR Lyrae stars are an unusual group of hydrogen-rich, low-mass giants found mostly in ancient globular clusters.

Cosmic lighthouse
These stars go through large changes in brightness every few hours, but Kepler data has helped to explain longer-period variations.



and oxygen. So there are two types of red giant: those that have started burning helium in their cores, and those that have not. From the outside it's very difficult to tell the difference, but now asteroseismology has given us a way."

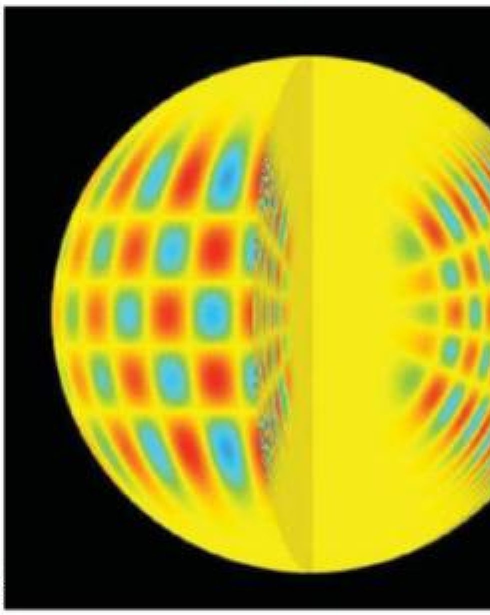
A key difference between the two types of red giant, in theory, should lie in the size and density of their cores - in the first phase the dormant helium slowly shrinks and grows denser, but once it ignites the pressure of escaping radiation should cause the core to expand again, and grow less dense. The changing core size and density should produce a measurable difference in the seismic oscillations affecting the two types of star.

"Indeed, it turns out that the red giants divide neatly into two groups based on observed properties known as mixed modes," continues Bedding. "We can match these with the two groups of red giants. This result is a beautiful confirmation of the theories of stellar structure and evolution. Until now, almost everything we know about the lives of stars has come from theoretical calculations but, as in all science, it's vital to test theory by using observations."

However, while asteroseismology has helped confirm some long-standing ideas about red giants, that's not quite the end of the story. "More extensive analyses of Kepler data by several groups has turned up a puzzle," admits Professor Bedding. "The rotation rates in the cores of these red giants, which we can also deduce from asterosesimology, turn out to be only about ten-times faster than the surface rotation. But theory predicts that the core of a red giant should rotate hundreds or even thousands of times faster than the surface. It's a puzzle that theoreticians are currently trying to solve, and is sure to shed new light on our understanding of stars."

And what of future research? Hardware failures meant the now-defunct Kepler was no longer able to point accurately towards its original small field of view, but Bedding is quick to see the bright side: "Kepler's K2 mission involved looking at a series of different fields for about 80 days each. This has a big advantage for asteroseismology because it will allow us to sample oscillating stars in many different directions in the galaxy, rather than just one."

> "Until now, almost everything we know about the lives of stars has come from theoretical calculations" **Prof Tim Bedding**



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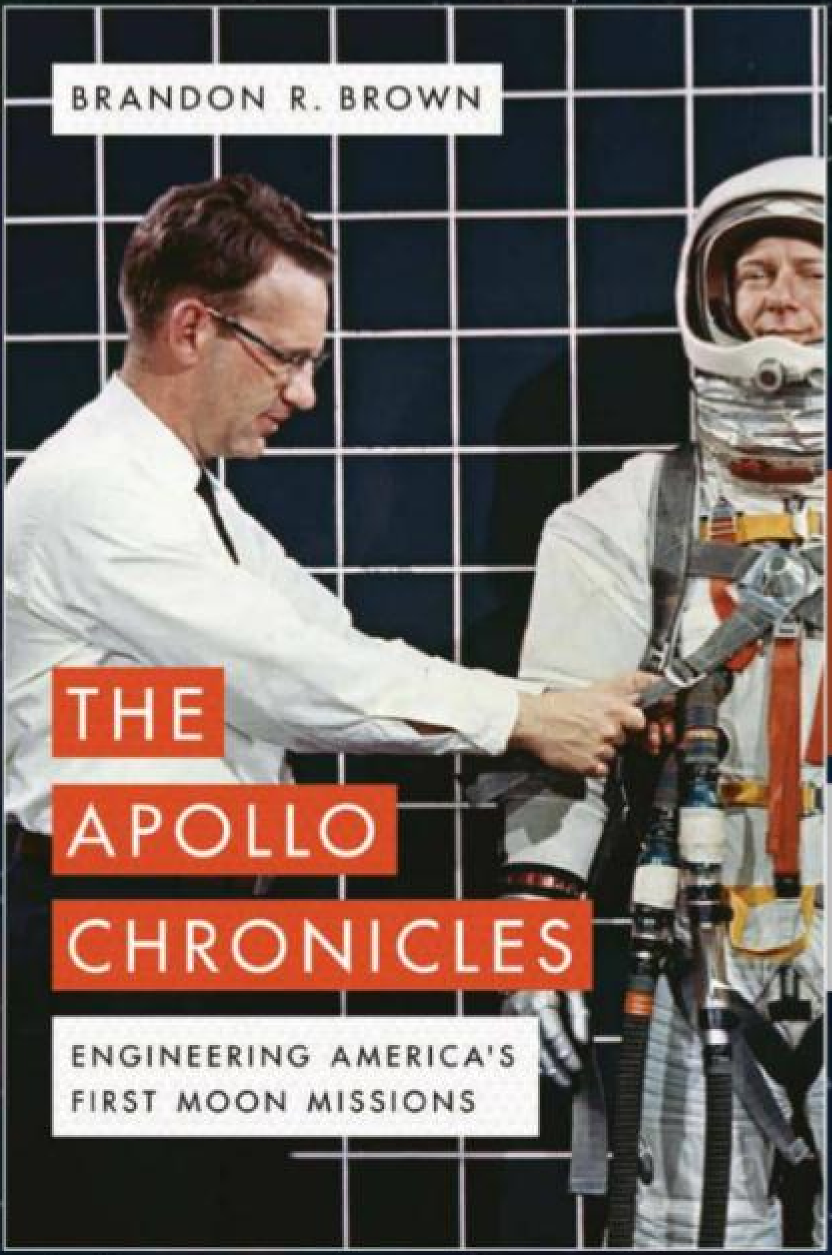

BRANDON R. BROWN

THE APOLLO CHRONICLES

ENGINEERING AMERICA'S FIRST MOON MISSIONS

Discover the untold stories of the engineers who built the first Moon-bound spacecraft

Read the interview with author Brandon R. Brown in this issue

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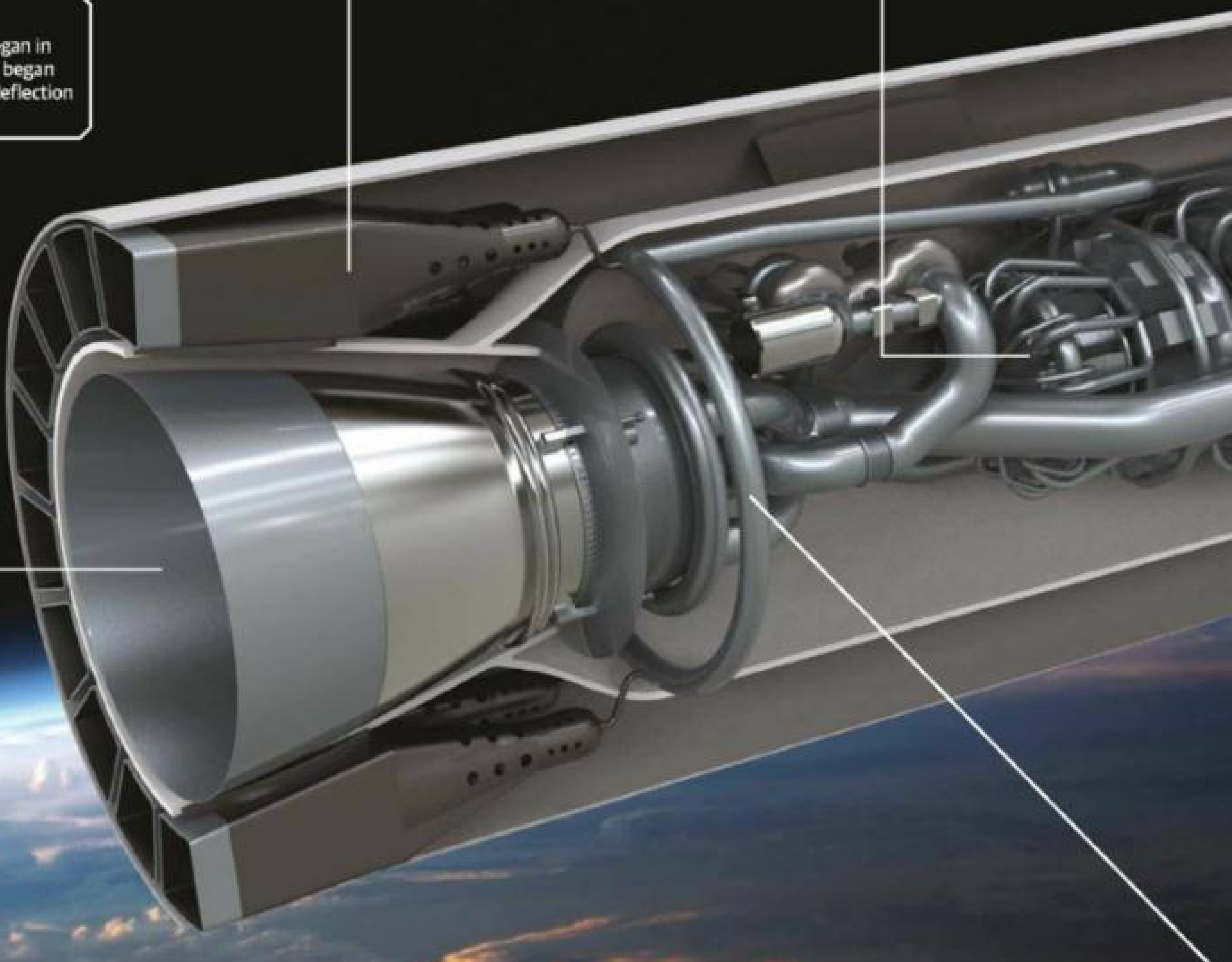


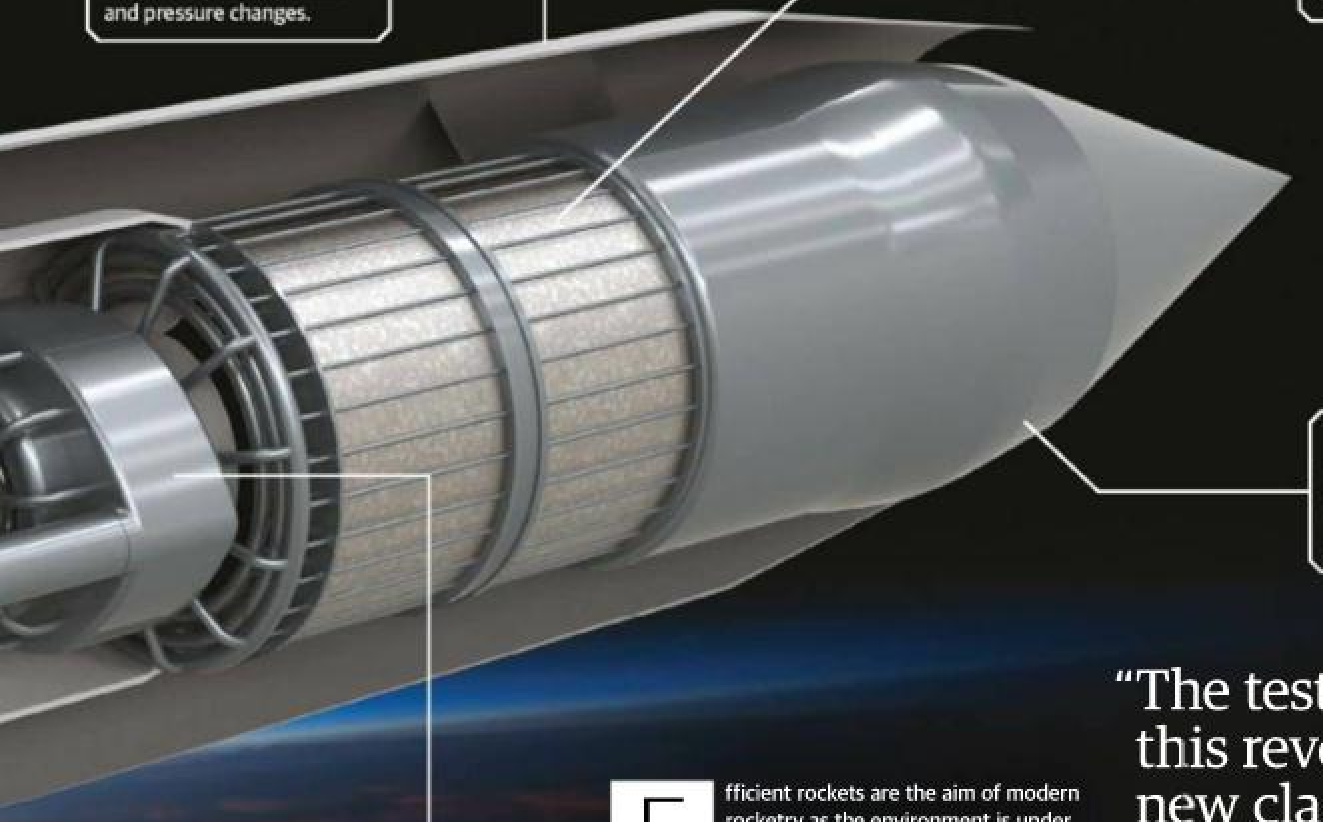
Ramjet
The ramjet soaks in the intake air leftover from the air-breathing propulsion system.

Turbine
A gas turbine, running on a helium hoop recycling system, powers the turbo-compressor.

Nozzle
Trails for the nozzle began in 2008 when engineers began testing an expansion deflection nozzle called STERN.

THE SABRE ROCKET

A joint ESA and UKSA engine that's able to breathe air is set to revolutionise spaceflight as we know it



Nacelle
The rocket's housing must be sturdy enough to keep everything in place and deal with the rapid temperature and pressure changes.

Pre-cooler
The hot intake air must be cooled and made suitable to power the rocket.

Supersonic air intake
The rocket requires the intake of air when travelling over three-times the speed of sound.

Compressor
The turbo-compressor powers the jet-engine stage of the rocket.

Rocket engine
After the rocket has passed five-times the speed of sound, the liquid-propellant rocket engine stage is ignited.

Efficient rockets are the aim of modern rocketry as the environment is under threat. The price of fuel is constantly on the rise due to a lack of resources, and this could be the answer: the first air-breathing rocket. Recently the European Space Agency (ESA) and the United Kingdom Space Agency (UKSA) have green-lit the next major series of tests for Reaction Engine Limited's SABRE.

SABRE is an acronym for 'Synergetic Air Breathing Rocket Engine', planned to be able to utilise atmospheric air during the initial 25 kilometres (16 miles) of the rocket's ascent. During this period a SABRE rocket could travel up to five-times the speed of sound, after which point it would switch to the pure-rocket mode to make the final climb into sub-orbital spaceflight.

ESA and the UKSA have invested a lot of time and money into the SABRE project in the past, with UKSA investing £50 million (approximately $63 million) and the ESA a further £8.9 million (around $11 million). "The positive conclusion of our preliminary design review marks a major milestone in SABRE development," comments Mark Ford, heading ESA's propulsion engineering section. "It confirms the test version of this revolutionary new class of engine is ready for implementation."

The SABRE rocket can be broken down into three sections: the pre-cooler front, the encore engine and the thruster chamber at the rear. The thruster chamber is the same iconic region as on any modern rocket that applies the thrust, but the core is what has been extensively examined by ESA and UKSA in their aforementioned tests. The core has to be capable of withstanding the pressures of both rocket and jet-engine capabilities as it shifts between air-breathing and rocket-engine modes.

The pre-cooler is also a pivotal part of SABRE. As its name suggests it cools the air it ingests in order to fuel the rocket in its air-breathing phase. As the air becomes thinner at high altitudes there is less jet fuel, hence why SABRE must then revert to rocket fuel. The pre-cooler has to be able to tame air that is coming in at high temperatures because of the supersonic – and even hypersonic – speeds. The most recent pre-cooler tests have proven very encouraging as it managed to rapidly quench airflow that was coming in at 420 degrees Celsius (788 degrees Fahrenheit) in a 20th of a second.

By creating a hybrid between the two aeronautic engines the rocket can save on the amount of fuel it needs to take, therefore reducing the mass of the payload. This has promising aspects not only for suborbital spaceflight, but also intercontinental supersonic travel, theoretically taking passengers from London to Australia in just 4.5 hours.

"As the home of the jet engine, the UK has a rich aerospace heritage and world-renowned skills and expertise," says Chris Castelli, director of programmes at UKSA. "This is an exciting landmark for Reaction Engines in the development of its SABRE engine, which could revolutionise both access to space and international travel by powering aircraft to five-times the speed of sound."

> "The test version of this revolutionary new class of engine is ready for implementation"

© NASA; Reaction Engines

NASA SCIENTISTS

HAVE THEY MADE ALIEN DNA?

While scientists and sci-fi writers have pondered what alien life might look like, a group of researchers reckon it's what's inside that really counts

Reported by David Crookes

© Tobias Roetsch, Jesper Klausen / Science Photo Library

When NASA formed in 1958, it sought to expand human knowledge of space. The US agency looked to further science and technology, develop and improve aeronautical and space vehicles and send humans on an unprecedented voyage of discovery. It also sparked interest in the potential of life on other planets. Today detecting alien life is an important part of NASA's planetary science missions, and its chief Jim Bridenstine says it's a high priority. Next year NASA is once again targeting the Red Planet, sending the Mars 2020 rover skywards so that it will touch down and collect samples for eventual return to Earth.

Meanwhile, the European Space Agency (ESA) is sending its own rover to drill below the surface of Mars in the hope of finding life buried underground. And the fact that it will bear the name Rosalind Franklin is proving to be rather apt.

It was this British chemist and X-ray crystallographer who helped discover the structure of DNA - the building blocks of life - assisting in laying down the principles to which scientists have worked to ever since. There is a fundamental understanding of what DNA is and how it presents itself here on Earth. Only it would now seem that unimagined forms of life may also exist.

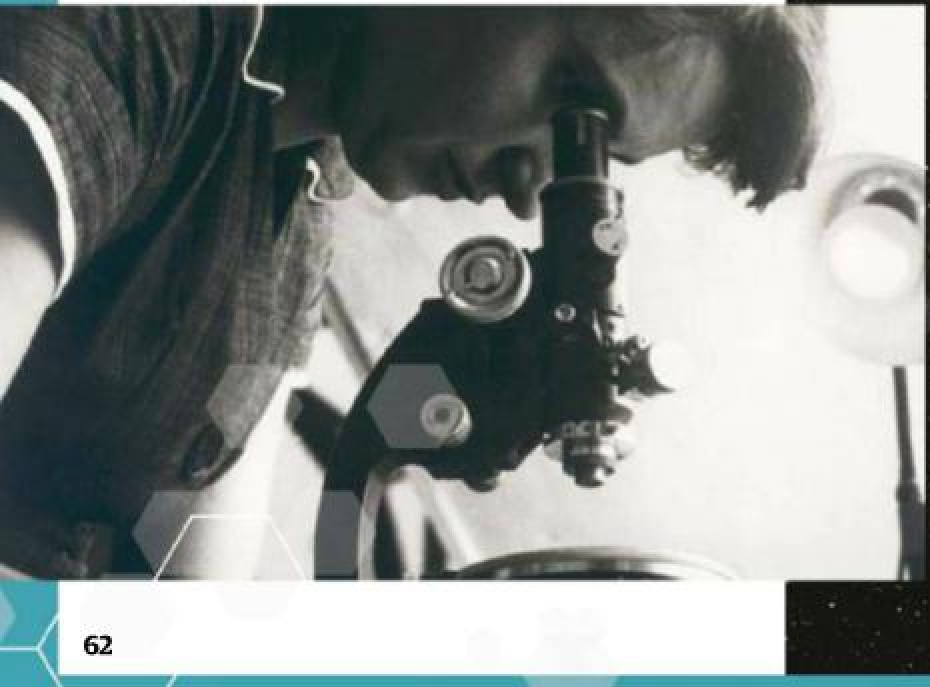
That's because scientists funded by NASA have developed a new type of molecular system that is able to store and transmit information just like DNA. It's entirely synthetic, and by no means a new life form, but it has stunning repercussions in the search for extraterrestrial life, not least because it presents a very real possibility that an alternative to DNA-based life may exist on other celestial bodies.

Far right (top): Astrobiologists have long been studying molecules and organic compounds in space to determine if life exists elsewhere in the universe

Far right: The top two base pairs show natural DNA, with the bottom two making up an additional synthetic pair as seen in hachimoji DNA

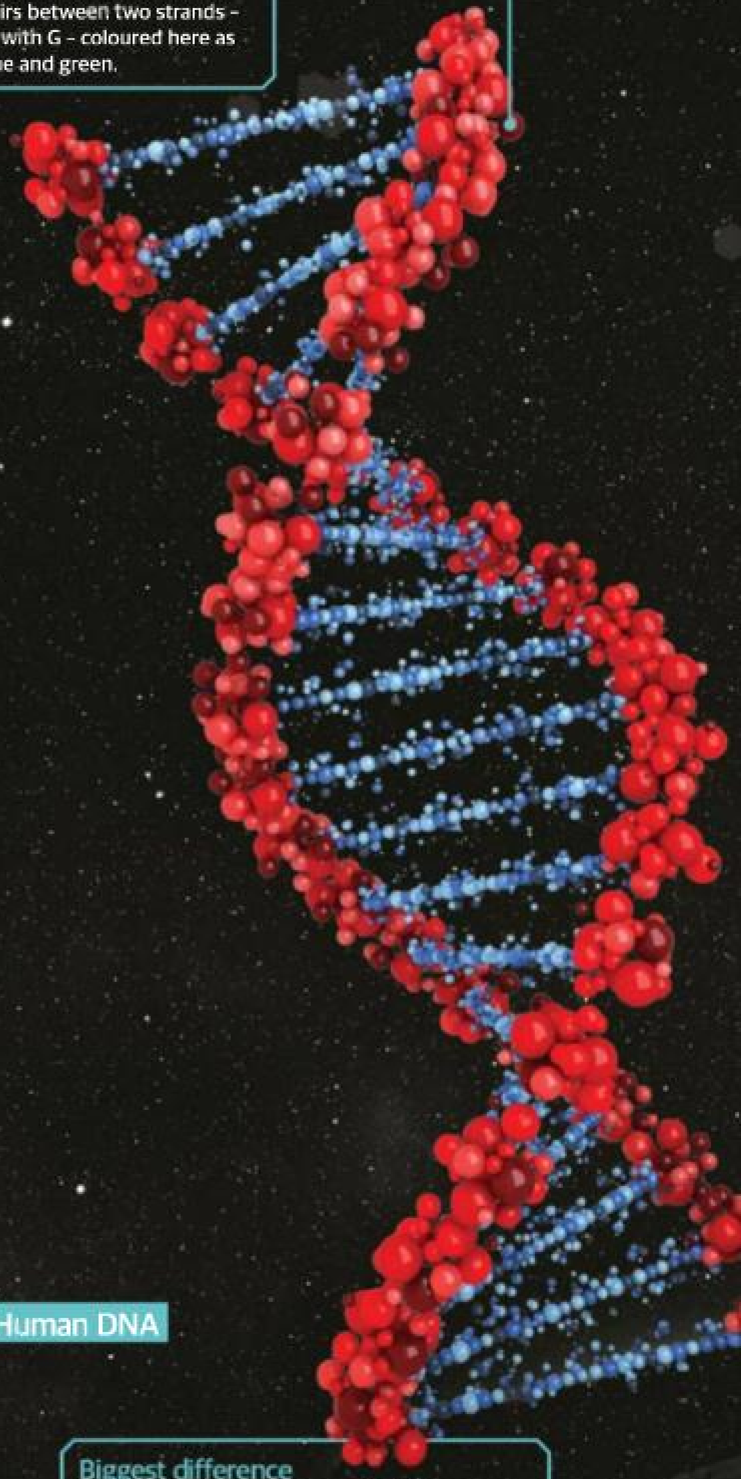
Below: Pictured in 1955, Rosalind Franklin also contributed to the study of coal, carbon and graphite

> "Scientists funded by NASA have developed a new type of molecular system that is able to store and transmit information"



Alien DNA vs Human DNA

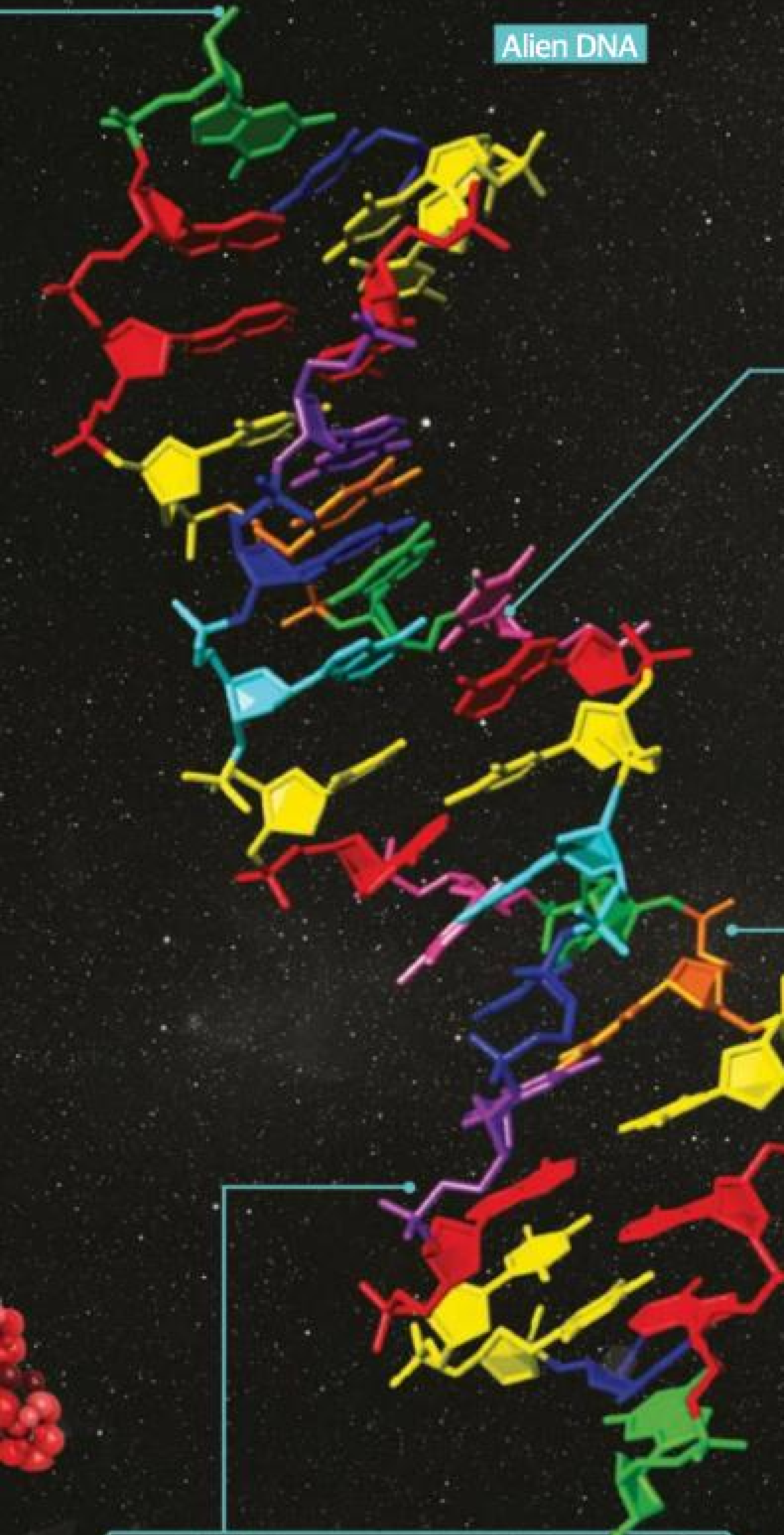
How does the synthetic hachimoji DNA compare with the natural DNA found in your own body?



Regular DNA
Human DNA contains four building blocks, or chemical bases: adenine (A), cytosine (C), guanine (G) and thymine (T). These cross-link in pairs between two strands - A with T and C with G - coloured here as red, yellow, blue and green.

Biggest difference
Perhaps the largest difference is that human, or natural DNA, is known to exist in life forms, but the 'alien' DNA has not been found here or elsewhere. It simply points to the potential for eight informational ingredients rather than four.

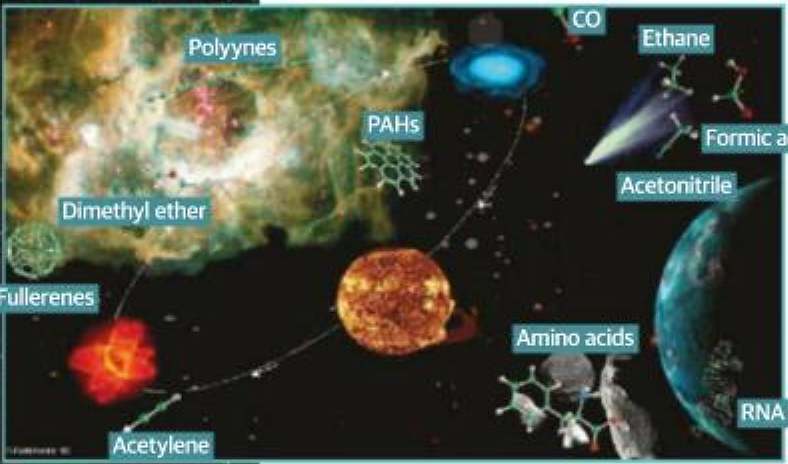
Double-stranded helix
Both the human and 'alien' DNA created by NASA-funded scientists have a double-stranded helix structure. The two strands of DNA are antiparallel - running in opposite directions - making them twist.

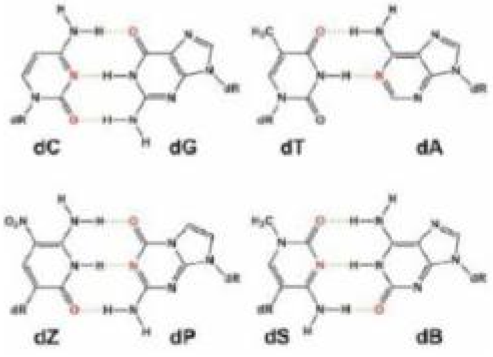


Alien DNA
Scientists have developed new synthetic bases that they have added to the natural DNA bases we know exist on Earth. In this image these additions are coloured pink, purple, cyan and orange.

New base pairs
Just as A only pairs with T and C only with G, forming hydrogen bonds in order to form two types of base pairs, so the synthetic nucleotide bases are explicitly linked. P binds with Z and B binds with S.

Four pairs
Whereas human DNA consists of two pairs of nucleotide building blocks, this 'alien' DNA - or hachimoji to give it its proper name - has four. When tested with enzymes hachimoji DNA strands translate into hachimoji RNA, allowing instructions to be carried to make proteins - just like natural DNA.





In that sense the breakthrough allows scientists to reconsider just what they could be looking for when they search for extraterrestrial life. But just what have the scientists done, and why is this important? To answer those questions it is crucial to understand the long-established fundamentals of DNA and how this new molecular system expands our ability to programme genetic systems into a new realm.

DNA - or deoxyribonucleic acid - was first isolated in 1869 by Swiss physician Friedrich Miescher, and it led to many decades of work. Scientists would establish DNA as a complex molecule existing in the nucleus of every cell, storing and transmitting genetic information, and they would discover that it consists of a deoxyribose sugar, phosphate and base. The base would be either adenine, thymine, guanine or cytosine - four important ingredients knows as nucleotides - and these were given the letters A, T, G and C.

In mid-March 1953, James D. Watson and Francis H. Crick worked out DNA's molecular model based on an X-ray diffraction image taken by Franklin, figuring that it was made up of two long molecules arranged in a spiral. The twisting strands of DNA were seen to combine into what is known as a double-helix structure, held together by complementary base pairs which always hook up in a certain manner. Thymine, for example, always pairs with adenine, and guanine always pairs with cytosine: T to A and G to C. Crick announced that the secret of life had been discovered.

Yet in February 2019, NASA previewed the results of further groundbreaking research that was to appear in *Science* magazine. It reported that a team

© ESA; MRC Laboratory of Molecular Biology; Leigh Prather / Alamy Stock Photo; Indiana University School of Medicine

led by Steven Benner at the Foundation for Applied Molecular Evolution in Alachua, Florida, had fabricated a new informational molecular structure - that is, something which functions like DNA and allows information to be stored and transmitted. The big difference is that this did not make use of four ingredients. Instead, it used eight.

"The Benner team took the existing four letters of DNA (A, T, G, and C) and four letters of RNA (A, U, G, and C) and made some chemical tweaks to form new letters that have approximately the same shapes and sizes as the existing letters," explains Dr Eugene Wu, associate professor of biology and biochemistry at Richmond School of Arts and Sciences.

Indeed, by adding four synthetic nucleotides identified as P, B, Z and S to the four present in DNA and RNA - the latter being ribonucleic acid, a large molecule which carries out the instructions encoded in DNA - the scientists successfully created four allowed base pairs rather than two. In other words, they could add two unnatural base pairs to the T to A and G to C arrangement of DNA that would mimic the structures of the ingredients in regular DNA and function in the same way. The result is a new double-helix structure that has a much greater capacity to store information.

"It was a matter of taking the existing base pair shapes and hydrogen bonding patterns from the Watson-Crick base pairs and changing the hydrogen bonding partners without substantially altering the shape," explains Wu, who was not involved in the research. "They designed the four new bases in such a way that they only pair with their intended partners, and not with other bases. Then it's just a matter of chemical synthesis and using existing DNA synthesisers to put the new letters into chains."

Benner's research project began 30 years ago, with the challenge being to reproduce the properties we value in living systems but on a molecular platform different to what prebiotic chemistry on Earth has delivered.

The research had two conceptual aims. First, it wanted to determine if alien life would use the same core molecules as life on Earth to support reproduction, evolution and adaptation, given it would have had an independent origin and different natural history. Second, it sought to synthesise an alternative genetic system to see if it was really possible. This proved to be successful.

As such, the team has given their creation a name, dubbing it hachimoji - 'hachi' means 'eight' and 'moji' means 'letter'. It is the first time that eight letters have been used in a DNA-like structure, with earlier attempts topping out at six. Importantly, the researchers developed a system that was stable, predictable and programmable. They can predict how it will behave at different temperatures and figure a set of rules.

"The discovery of four new bases for genetic informational storage is really quite clever," says Wu. "If you could imagine Watson and Crick working out the rules for making base pairs in DNA in 1953, this would be like taking those same rules and just moving the hydrogen bonding partners around.

"It immediately begs the questions, could life contain an alphabet of more than four letters and, if so, why did we end up with A, T, G, and C? In addition the research results constitute an important breakthrough in the efforts to someday redesign life as we know it."

As it stands, Benner tells us that the system created in the lab has four of the five features valued in a biopolymer that can support life. "It stores information in a rule-based, predictable

> "The results constitute an important breakthrough in the efforts to someday redesign life as we know it" **Dr Eugene Wu**

Where are we likely to find life?

Venus

Venus is dry and incredibly hot, making it a very inhospitable planet, but some scientists suggest it would have been habitable more than 2 billion years ago when it was far more temperate. There's even a suggestion life retreated to the planet's cooler clouds - which are mostly sulphuric acid - and that life could remain there today!

Mars

It's a long-held dream that the Red Planet harbours life - David Bowie even sang about it. Although it's yet to be found, there's still great optimism. The past existence of liquid water - still found as low-volume liquid brine - gives hope. Scientists have also detected methane, suggesting an active surface.

Ceres

Ceres is a dwarf planet which lies between the orbits of Mars and Jupiter, and scientists are keen to discover if it has the potential for life. They're particularly excited because Ceres has water. NASA also found that it is rich in organic matter and contains crucial chemicals such as ammonium.

Europa

The icy world of Europa orbits Jupiter, and while it may be a fraction smaller than Earth's Moon, it has huge potential for life. There is an abundance of liquid water beneath the surface and, in 2013, NASA detected 'clay-like minerals' on the moon's surface. These are associated with organic matter on Earth.

Enceladus

Not only does this moon of Saturn have a global salty ocean beneath its icy crust that is likely being heated by thermal effects, the Cassini-Huygens probe in 2005 detected carbon, nitrogen, oxygen and hydrogen. There are also large geysers of water vapour at the south pole, all of which are rather exciting.

Titan

Another one of Saturn's moons – and the largest of the 62 – Titan has a thick, chemically active atmosphere which is rich in carbon compounds. It's therefore one of the most Earth-like of worlds and, since it has stable liquids on its surface and a hydrological cycle, the chance of life is one scientists are keen to explore.

Above: NASA's statement on the hachimoji breakthrough questions whether moons such as Europa may contain life which doesn't use our DNA

Far left: A NASA researcher performs DNA and RNA sequencing on microbes, but have we been too focused on looking for what we know exists?

fashion, and we show it gives predictable double helices with thermodynamic rules as good as with four-letter DNA," he says. "That information can be transferred to other biological molecules. Here, we found enzymes that allow the synthesis of eight-letter RNA by transcription of eight-letter DNA."

He goes on to say that, both directly and as transferred, the information can confer a selectable phenotype: "Here, the selectable phenotype was green fluorescence." He adds that "the information can evolve. This was shown by multiple crystal structures. Biochemists in the laboratory can set up in-vitro selection systems that will force hachimoji DNA and hachimoji RNA to evolve to have many selectable phenotypes.

"As an example, we have evolved pieces of hachimoji DNA to bind to breast cancer cells, liver cancer cells and anthrax toxin. We are now evolving pieces of hachimoji DNA that are adapted to selectively cut proteins that are responsible for disease."

Scientists can certainly start to think about the implications of elegantly increasing the number of DNA building blocks from four to eight. "It dramatically expands the information density of nucleic acids," says Professor Michael Jewett of Northwestern University. "The fact that the high-resolution crystal structures for this new eight-letter hachimoji DNA code are similar to the normal four-

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“The approach described here could help bypass the limitations of natural translational biochemistry” **Professor Michael Jewett**

What could this mean for the future of hunting for life?

“It is inadequate to simply speculate about what alien life might look like. It is necessary to go into the laboratory with specific, actionable chemical structures and see how they perform”
Steven Benner, distinguished fellow at the Foundation for Applied Molecular Evolution

“This new work will help us to develop effective instruments and experiments that will expand the scope of what we look for”
Lori Glaze, acting director of NASA’s Planetary Science Division

“Incorporating a broader understanding of what is possible in our instrument design and mission concepts will result in a more inclusive and therefore more effective search for life beyond Earth”
Mary Voytek, senior scientist for astrobiology at NASA headquarters

“The discovery that DNA with eight nucleotide letters is suitable for storing and transmitting information is a breakthrough in our knowledge of the range of possibilities necessary for life”
Andrew Serazin, president of Templeton World Charity Foundation

Above left: ESA’s ExoMars rover has been named after Rosalind Franklin, whose work was crucial for the understanding of DNA

Top: Many asteroids and comets have smashed into planets - could they have delivered the key ingredients of life?

Above: An image showing organic material on Mars that could be a biomarker sign of past life

Right: Phosphorus - a key component of DNA and cell membranes - was discovered on the Rosetta comet

letter code used in human DNA additionally makes possible many transformative applications, from digital DNA storage to molecular evolution.

“For example, efforts to repurpose ribosomes to expand the range of genetically encoded chemistry rely on expanding these codons that could be reprogrammed. In principle a hachimoji system could extend the codon space in full life forms from 64 to 512. Thus, the approach described here, if it could be used in living systems, could help bypass the limitations of natural translational biochemistry for new biocontainment and manufacturing applications.”

Hachimoji also impacts the ongoing search for life, with Benner suggesting the work “expands our understanding of the types of molecules that might store information in extraterrestrial life on alien worlds”.

“More specifically, as NASA designs missions to search for alien life in the cosmos, should it be looking for DNA as if DNA is the only biopolymer that can support Darwinism? Or can many biopolymers support Darwinism, requiring NASA missions to construct their search strategies more broadly?” he queries.

Indeed, according to NASA it raises many questions about the nature and structure of life elsewhere. Inhospitable environments that would prevent life as we know it on Earth from flourishing could see an abundance of different types of life forms since it points to there being a potential for alternative genetic systems. Scientists need to be alert to the possibility that other worlds do use our DNA, and they need to work out ways of being able to recognise it. Researchers also suggest that hachimoji DNA could develop clean diagnostics for

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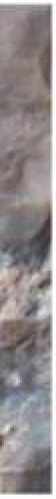


human diseases and open the way for DNA digital data storage. But could it even be used to create full life forms?

"The idea of creating a new life form that lives by a different code comes immediately to mind," says Wu. "With eight letters instead of four, a three-letter codon could code for 8x8x8, or 512 different possible combinations. Even a two-letter codon could code for 8x8, or 64 different combinations, same as the existing biological genetic code.

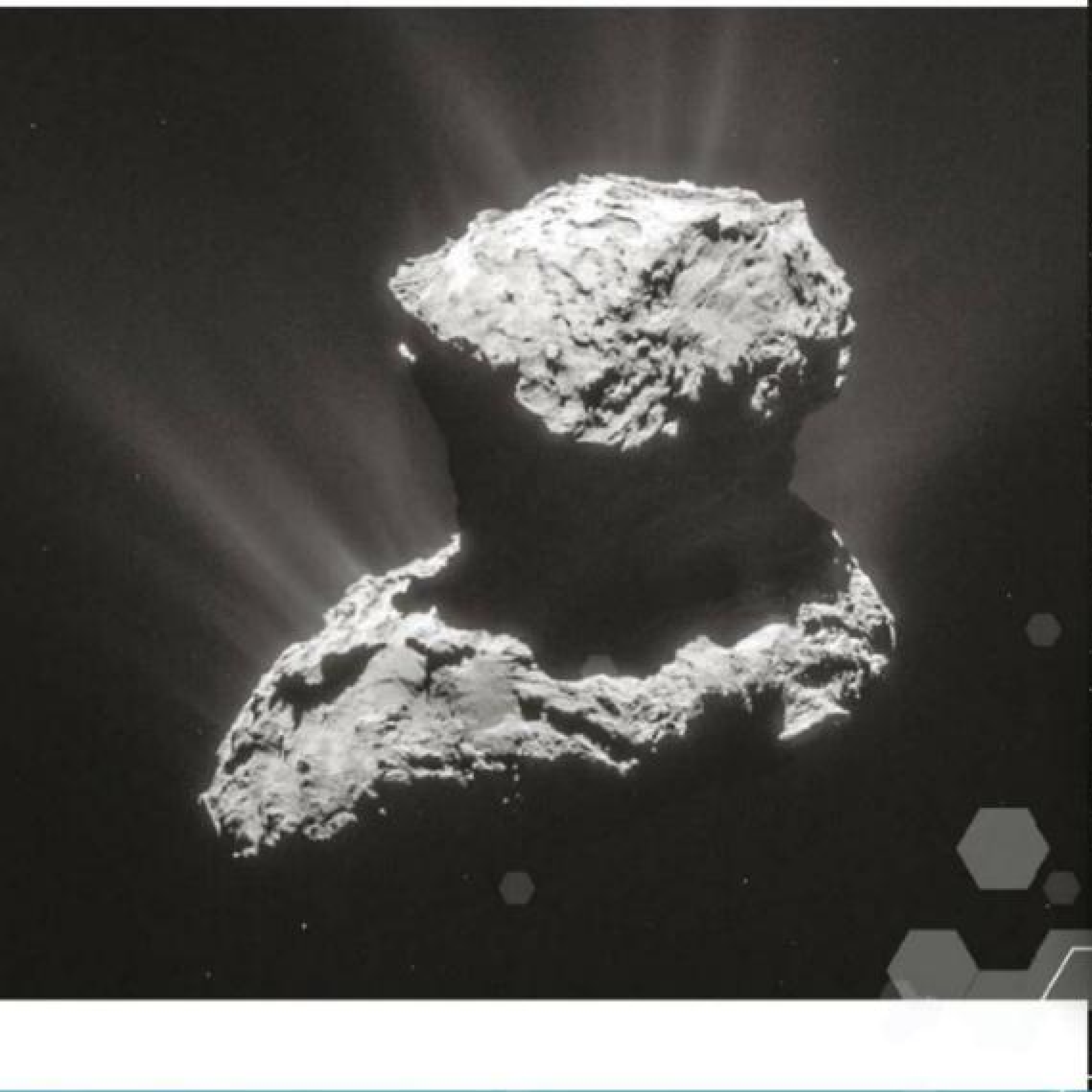
"But a cell containing a two-codon, eight-letter code would be completely incompatible with existing life, even if every single protein were the same. The first thing that could be done would be to incorporate an unnatural amino acid into proteins by matching it with a three-letter codon that uses hachimoji RNA. Even that is a challenging biochemical engineering project, but certainly conceivable."

So far Benner and his team have developed synthetic enzymes that copy hachimoji DNA into hachimoji RNA, allowing the transfer of stored information so that instructions can be carried out within an organism. They haven't, however, sought to take things further by actually creating something that could be self-sustaining - and although fears have been expressed that the synthetic DNA could leak from the laboratory and cause an alarming biohazard, the system actually needs a steady supply of unique building blocks and proteins that are only found in the lab. "It must be nurtured constantly by attentive scientists," Benner says.

In any case, the researchers are also not claiming that this exact system exists in the universe, and it is ultimately an exercise in showing what is possible: the beginning of a larger journey and something of an awareness campaign. But what could DNA actually be like on other worlds? "That," says Wu, "is a much bigger question."

"We can say that alien life might have eight-letter DNA on other worlds," adds Benner. Certainly, if the fundamental idea of evolution holds true for other worlds, a genetic system would have to at least be able to store, transmit, express and change information.

"The simplest way to do this would be through polymers of molecules with a backbone where the connections between building blocks are made," he says. "One could imagine a simpler system with only two letters in the genetic alphabet. Also, if other worlds have little or no accessible phosphorus, their informational molecules would be very different than DNA and RNA. It's even possible that the informational molecule on another world might be branched or three dimensional, not just a linear polymer. Hard to imagine when we've only got the one way that worked here."



Missions on the hunt for alien life

Mars 2020

Mission aims

To seek signs of past habitable conditions on Mars and search for signs of microbial life.

This rover by NASA's Mars Exploration Program is set to launch next summer and begin investigations in 2021. It will collect dozens of samples of surface soil and rock cores which will eventually be sent back to Earth for analysis.

Transiting Exoplanet Survey Satellite

Mission aims

To find planets outside of our Solar System, including those that may support life.

TESS launched on 18 April 2018 to search for exoplanets around nearby stars. A catalogue has since been created noting potentially habitable planets; the idea is that it helps researchers find the most promising candidates.

Europa Clipper

Mission aims

To conduct a reconnaissance of Jupiter's moon Europa to check for signs it could harbour life.

Due to launch in June 2023, the craft will orbit Jupiter and study Europa in light of the Galileo probe having noted a subsurface ocean. Radar will determine the thickness and composition of its icy shell.

OSIRIS-Rex

Mission aims

To sample 60 grams of the asteroid 101955 Bennu and return it to Earth for analysis.

Although scientists have been keen to study Bennu to understand more about how the Solar System has formed and evolved, the mission has discovered signs of water. It will likely offer clues about the origins of life on Earth.

APOLLO'S BUMPS IN THE ROAD TO SPACE

The ride to the Moon was never a smooth one, but the setbacks only made the accomplishment more impressive. Brandon Brown tells **All About Space** about some of the challenges that engineers had to overcome

Interviewed by Lee Cavendish

INTERVIEW BIO

Professor Brandon Brown

Brandon Brown is a professor of physics at the University of San Francisco, United States. His new book – *The Apollo Chronicles: Engineering America's First Moon Missions* – tells the story of the Apollo program from first to last in a well-written and engaging way.

The motivation behind the book was to understand what his father was doing for NASA as an engineer, but there wasn't any literature that covered the whole project from such a perspective. This was the genesis for his comprehensive guide to the impressive engineering feats that occurred in the United States' amazing Apollo space program.

In *Apollo Chronicles* you talk about Wernher von Braun, who previously worked for Nazi Germany in World War II. Was there much convincing needed in the United States in order to allow him to work on rockets in their space program?

To the best I could find, no. In fact, information about his past in World War II started coming out in Europe during the peak of the Apollo program, or the crest of it, and von Braun was very worried about some of these reports in German getting translated to English and then getting released in the United States. NASA and the US government told him: "Don't worry about it. It's not going to come over here."

From his first days in America, von Braun was surprised by the hospitality of former enemies. With calculated effort, he became a sort of media darling within ten or so years. He wrote feature articles and regular columns in leading magazines of the day. He even helped Walt Disney produce TV shows about humanity's future in space. Many eventual NASA engineers would credit these shows for early inspiration.

At the start of the Apollo program was the Apollo 1 disaster. What impact did that have on the mission at the time?

I was shocked when I got into it. If you plot out the eight years that [former president John F.] Kennedy made the announcement [to head into space] – which shocked many of the engineers, by the way – to the first successful Moon landing, this came in

© NASA

Left: The ground-based NASA team celebrates the safe touchdown of Apollo 13

Top right: The launch of Sputnik 1 in 1957 sent the Soviet's into pole position in the Space Race

Far right: (From left to right) Gus Grissom, Ed White and Roger Chaffee tragically lost their lives in the Apollo 1 disaster

Bottom right: Former President John F. Kennedy made the announcement to go to the Moon in 1961

1967 when they were ready to start testing the first Apollo modules and so on.

It was really a shock. It took a lot of the innocence out of NASA and a lot of its vibrant, youthful exuberance went away. People realised, as von Braun said: "Now people know we're not in the business of selling shoes." If you have a defective shoe that's one thing, but a defective capsule can kill people. So there was great criticism.

In the immediate aftermath people thought, 'Wow, we're not going to achieve Kennedy's goal. Full stop.' But they [NASA] quickly gathered themselves, made 125 different modifications to that command module and amazingly, by the end of the year, they had put an Apollo modified module up into space.

Afterwards NASA had great success, up until Apollo 13 where an oxygen tank blew up on the way to the Moon. What role did the ground-based engineers have in getting the astronauts back to Earth safely?

They were pretty critical to the survival of that mission. It kind of went into round-the-clock engineer overdrive on Earth once they had the accident. There was a key young engineer who had solved several problems for them - I tell the story in my book - and he was just getting out of the shower and he got a call from the main NASA centre saying: "Hey, we're having all these problems. We think we must have some instrument readings that are wrong, because they make no sense."

He quickly heard the different sets of data and he told them: "You're each too close to your own monitor, and if you look at it all together, that capsule is dying. We have a real problem." It took a bit of time to figure out what was actually wrong; they were losing oxygen. So the engineers worked around the clock on all sorts of problems.

> "If you have a defective shoe that's one thing, but a defective capsule can kill people. There was great criticism"

Are there examples of engineers fixing problems before they became major issues?

Absolutely. I illustrate one in the book where a fuel tank had shown a flight rupture during a test. The more middle-management engineers said: "Well most of these tanks are fine. The company said this is because someone left a fingerprint on the inside of the tank and there was a chemical reaction, and that fingerprint led to the problem that led to the crack." Then young engineers went and looked at the tank physically and said: "That's impossible. Only a monkey could get a paw into this tank to leave a fingerprint. The company's wrong."

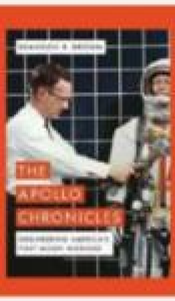
They kept making noise, and due to the very healthy culture of NASA at the time - where everyone who had a valid technical point was heard out - eventually the higher-level, older management agreed to run a bunch more tanks in a test, and a bunch of them failed catastrophically. So if the younger engineers hadn't made this point, that the company manufacturing the fuel tank were mistaken about the source of the problem, they almost assuredly would have lost one of those on an Apollo mission, and that would have been deadly if a little fuel tank had ruptured on the way to the Moon.

What was the most surprising aspect about the Apollo program you found out when writing your book?

What I most remembered is the chaos of 1962. This is in the year after Kennedy's announcement, and I was surprised that many engineers had said: "It was the dumbest thing I had ever heard, the idea of going to land on the Moon."

One engineer described it as he felt like they had just barely gotten on their feet like a toddler, and now their president was saying we're going to run a marathon in a couple of years. That was surprising. I always assumed when Kennedy made his announcement, all the engineers would have been very excited and thought: "Here we go! We have support for this bold mission." But it was a little different from that.

Read more about the outstanding engineering work that took the first pair of humans to the Moon, and the rest that followed, in Brandon Brown's guide through the space program, *The Apollo Chronicles: Engineering America's First Moon Missions.*



HUNT FOR LIFE

Why haven't we detected other civilisations?

It's a puzzle; we do expect these civilisations to exist. After all, there could be a trillion planets in the galaxy – maybe more. You don't need any special knowledge to consider this question, and I've explored it with lots of people over the years. I've found they often frame their thinking in terms of the barriers that would need to be cleared if a planet is to host a communicative civilisation. They usually identify four key barriers. The first is habitability – we need a terrestrial planet in that 'Goldilocks zone', where water flows as a liquid.

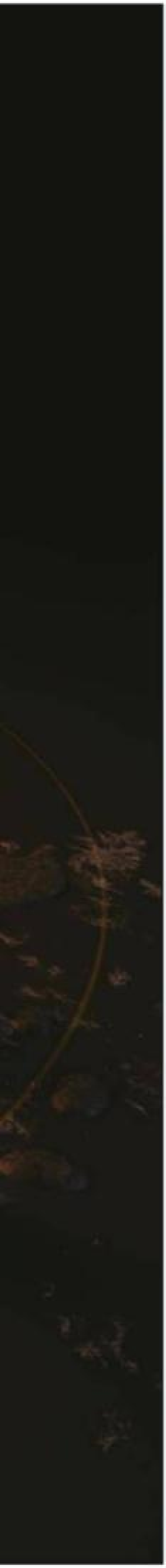
Abiogenesis – the creation of life from non-life – that's the second barrier. The basic building blocks of life aren't unique to Earth: amino acids have been found in comets, complex organic molecules in interstellar dust clouds, water in exoplanetary systems. The development of technological civilisation is a third barrier. Some say we already share our planet with alien intelligences.

Communication across space – that's a fourth barrier. Maybe advanced civilisations choose to explore inner space rather than outer space, or engineer at small distances rather than large. Or maybe they just don't want to risk an encounter with a potentially more advanced and hostile neighbour. There'll be worlds where, for whatever reason, civilisations either stay silent or don't spend long trying to communicate.

Stephen Webb is a popular science writer. His books cover a range of topics including astrobiology, cosmology, observatories, physics and science fiction

The first barrier is having water exist as a liquid, which is dependant on the distance from a star

© University of Portsmouth



'Oumuamua's fleeting pass didn't allow much time to analyse it properly

ASTEROIDS

What exactly is 'Oumuamua?

We firmly believe it's likely to be a leftover archaeological remnant from the process of the birth of another planetary system; some celestial driftwood. Some think 'Oumuamua formed very close to a star much denser than our own, and the star's tidal forces shredded planetary material early in the stellar system's history. Others suggest that maybe this is something that formed during the death throes of a star, perhaps during a supernova explosion as planetary material got shredded.

Whatever it is, we believe it's a natural object, but we can't actually prove that it's not something artificial. The colour, the strange shape and the tumbling motion could have other explanations. While we don't believe this is alien technology, why not do the obvious experiment and search for a radio signal? That's exactly what the Breakthrough Listen project did, but so far 'Oumuamua has remained completely quiet.

Could we send a craft to 'Oumuamua and answer this question once and for all? Yes, we do actually have the technology, but it would be a long and expensive voyage, and we would get so far from the Sun that the final trajectory would be difficult.

Karen J. Meech is an astronomer at the University of Hawaii

SPACE EXPLORATION

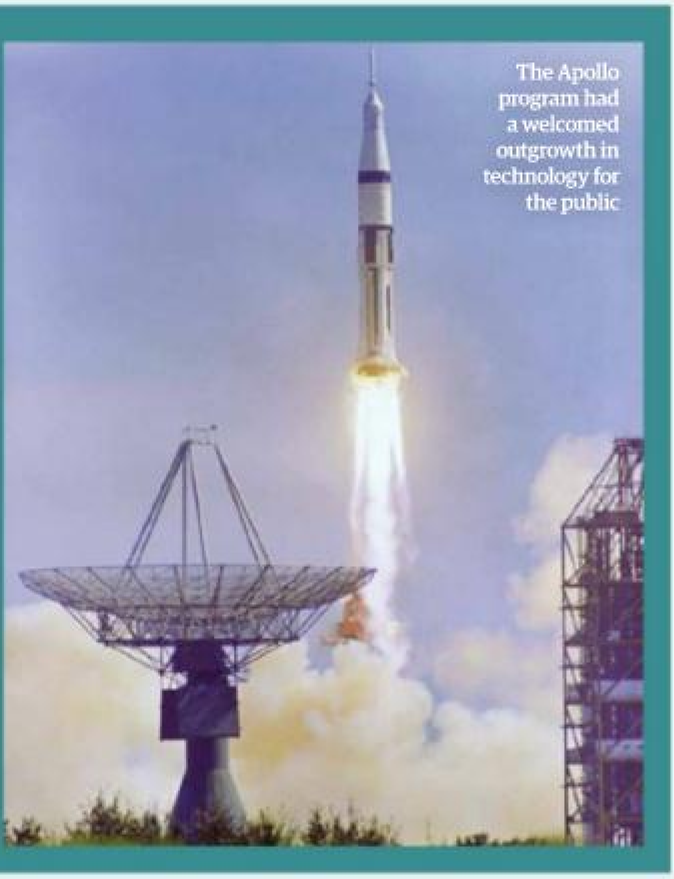
Why do we need space exploration?

We live in difficult and challenging economic times. One of the first victims of difficult economic times, I think, is public spending of any kind, but certainly in the firing line at the moment is public spending for science, and particularly curiosity-led science and exploration.

Our exploration of the Solar System has taught us that the Solar System is beautiful. It may also have pointed the way to answering one of the most profound questions that you can possibly ask, which is: "Are we alone in the universe?" Is there any other use to exploration and science, other than just a sense of wonder?

What's also not often said about space exploration, about the Apollo program, is the economic contribution it made. While you can make arguments that it was wonderful and a tremendous achievement and delivered pictures like this, it cost a lot, didn't it? Well, actually, many studies have been done about the economic effectiveness, the economic impact of Apollo. The biggest one was in 1975 by Chase Econometrics, and it showed that for every $1 spent on Apollo, $14 came back into the US economy. So the Apollo program paid for itself in inspiration, in engineering achievement and, I think, in inspiring young scientists and engineers 14-times over. So exploration can pay for itself.

Brian Cox OBE is a popular science communicator



The Apollo program had a welcomed outgrowth in technology for the public

© NASA/JPL-Caltech; ESA; NTNU; University of Hawaii (UH/IfA); NTNU; Royal Astronomical Society

SPACE EXPLORATION

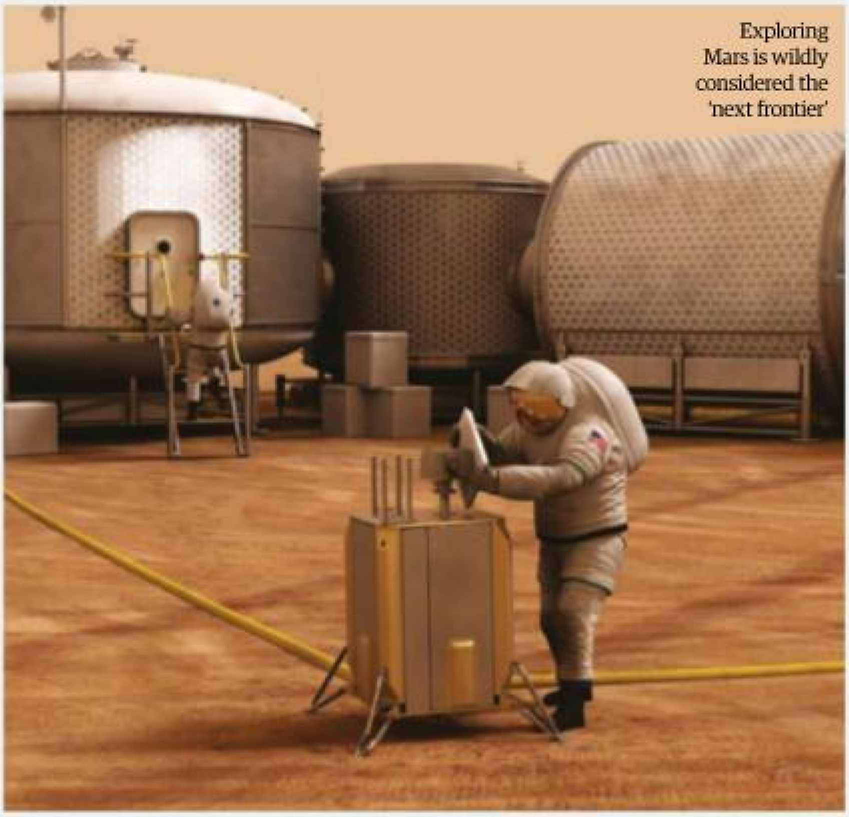
Why should we colonise other worlds?

About 12 years ago, I gave a TED talk on '10 ways the world could end suddenly'. We are incredibly vulnerable to the whims of our own galaxy. A single large asteroid could take us out forever. To survive we have to reach beyond the home planet. Think what a tragedy it would be if all that humans have accomplished was suddenly obliterated.

And there's another reason we should go: exploration is in our DNA. 2 million years ago humans evolved in Africa, then slowly but surely spread out across the entire planet by reaching into the wilderness that was beyond their horizons. This stuff is inside us. And they prospered doing that. Some of the greatest advances in civilisation and technology came because we explored.

Think for a moment what we had when John F. Kennedy told us we would put a human on the Moon. He excited an entire generation to dream. Think how inspired we will be to see a landing on Mars. Perhaps then we will look back at Earth and see that we are one people instead of many, and perhaps then we will look back at Earth, as we struggle to survive on Mars, and realise how precious the home planet is.

Stephen Petranek is an award-winning journalist



Exploring Mars is wildly considered the 'next frontier'

SPACE EXPLORATION

What is the future of space travel?

In the last six decades, space has opened up to us. Low-Earth orbit, this tiny slither of space about 400 kilometres (250 miles) up, is no longer the purview of governments and large aerospace companies. New space companies are taking advantage of what we call the democratisation of space. Why is access to space becoming easier? In part it's because the cost to get to space is dropping significantly, and there are three main reasons for that. The first one is reusability. Secondly there is also a rapid growth in production and deployment of very small spacecraft;

Virgin Galactic's spaceport will send members of the public into space

Did you know?

Dennis Tito, an American engineer, was the first man to self-fund a trip into space in 2001. He spent almost eight days in Earth orbit aboard the ISS.

© NASA; Virgin Galactic; Adrian Chesterman; Royal Astronomical Society; ICRAR

Small doses of antimatter could provide incredible propulsion

ASTROPHYSICS

What is antimatter, and how could it help travel around the universe?

In the 1700s we built the chronometer that allowed us to travel the seas. In the 1900s the Wright brothers developed flight and allowed us to master the skies. If we really want to explore beyond our Solar System, we're going to have to come up with a new tool.

Antimatter was first predicted by Paul Dirac. He was struggling with two relatively new concepts: special relativity, which describes life at really high speeds and the speed of light, and quantum mechanics, which describes the world of atoms and molecules. When he was solving this relativistic quantum mechanics equation he came out with two answers, a positive energy and a negative energy from these particles, the negative being antimatter.

An interesting characteristic of antimatter is annihilation. If you have an antimatter particle and a matter particle and they get close enough together, they'll both disappear and turn into pure energy. In fact, if you had a gram of antimatter, it would have the same amount of energy as a 80 kilotonne nuclear weapon. Not only does antimatter have incredible promise as a fuel for spacecraft, but this has some pretty significant applications in the future of energy.

Ryan Weed is the CEO of Positron Dynamics

they are called CubeSats. The third reason is that we are developing much higher capability in much smaller packages – if time is money in business, then mass is money in the space business.

That is opening up the space environment, so the exploration of the past is being replaced by space commerce, at least at low-Earth orbit. There are private spaceports opening up all around the [United States] and a few internationally. Spaceports embody space tourism, which is a world in which space becomes accessible to you and to me. When Virgin Galactic explore outer space and everything goes well, within about a year they will have flown three-times as many people into space then have gone in the previous 60 years.

Private commercial enterprise taking over low-Earth orbit allows government-led enterprises, such as NASA and so on, to focus on creating the new phase of exploration. They take the next steps to push those frontiers much further.

David Alexander OBE is director of Rice University's Space Institute

©Rice University

ASTRONOMY

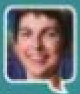
What do radio observations reveal about the centre of the Milky Way?

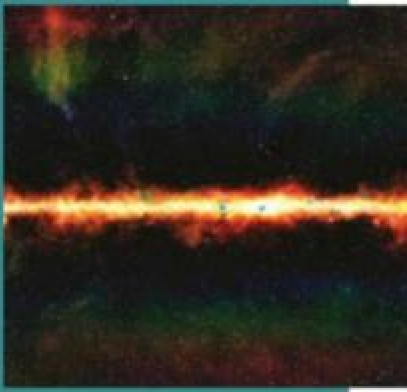
Radio is really brilliant. It allows us to peer much more deeply. It doesn't get stopped by dust, so you can see everything.

Well, we do see something interesting in the Milky Way. All that dust has gone, so it's not a problem. But the view is very different. The centre of the Milky Way is aglow, and this isn't starlight. This is a light called synchrotron radiation, and it's formed from electrons spiralling around cosmic magnetic fields. The plane is aglow with this light.

We can also see strange tufts coming off it, and objects which don't appear to line up with anything that we can see with our own eyes. Radio waves have a wavelength that's long, and that makes their resolution poorer.

I've spent a long time calibrating it, running millions of CPU hours on supercomputers and trying to understand that data. And with the Murchison Widefield Array (MWA) data, we've performed a survey of the entire southern sky – the GaLactic and Extragalactic All-sky MWA Survey (GLEAM). The resolution has gone up by a factor of a hundred. We now have a technicolor view.


Natasha Hurley-Walker is an early-career astronomer at Curtin University, Australia



PLANETS

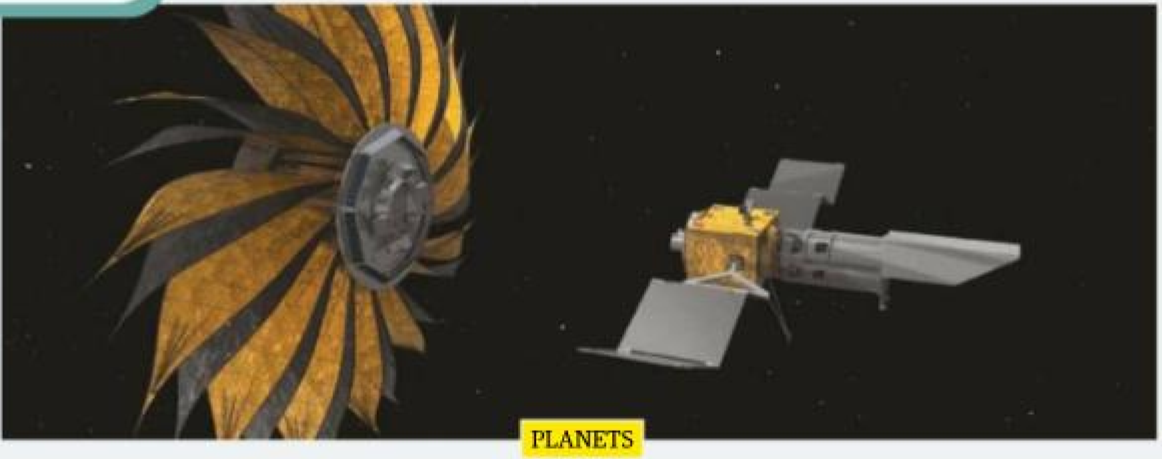
Could Earth evolve to look like Mars?

Well, every minute, 400 pounds (180 kilograms) of hydrogen and almost seven pounds (three kilograms) of helium escapes from Earth into space. This is gas that is going off and never coming back.

But the Earth is not alone in undergoing atmospheric escape. Mars, our nearest neighbour, is much smaller than Earth, so it has much less gravity with which to hold onto its atmosphere. Even though Mars has an atmosphere it's much thinner than the Earth's, and atmospheric escape plays a role in Mars being red. That's because we think Mars used to have a wetter past, and water broke up into hydrogen and oxygen. With hydrogen being so light, it escaped into space. The oxygen that was left oxidised or rusted the ground, making that familiar rusty, red colour that we see.

In the far future, the Sun is going to get brighter. As that happens, the heating that we find from the Sun is going to become very intense, and gas is going to stream off from the Earth. And so what we can look forward to, or at least prepare for, is the fact that in the far future, the Earth is going to look more like Mars. Our hydrogen, from water that is broken down, is going to escape into space rapidly, leaving an incredible dry world."

Anjali Tripathi is an astrophysicist who most recently worked at Harvard University



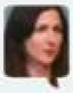
PLANETS

How will we find planets that support life?

There are actually many ways to find planets, several different ways, but the one that I'm most focused on is how we can open a gateway so that in the future, we can find hundreds of Earths. We have a real shot at finding signs of life, and actually, I finished leading a two-year project in this very special phase of a concept we call the 'starshade'.

The starshade is a very specially shaped screen, and the goal is to fly that starshade so it blocks out the light of a star so that the telescope can see the planets directly. It's shaped like a giant flower, and the concept is that a starshade and telescope could launch together, with the petals unfurling from the stowed position. The central truss would expand, with the petals snapping into place. This has to be made very precisely, literally the petals to microns, and they have to deploy to millimetres. This whole structure would have to fly tens of thousands of kilometres away from the telescope. It's about tens of metres in diameter.

The goal is to block out the starlight to incredible precision so that we'd be able to see the planets directly. And it has to be a very special shape because of the physics of defraction.



Sara Seager is a professor at the Massachusetts Institute of Technology (MIT) and is trying to hunt down Earth's twin

SOLAR SYSTEM

What can we learn from near-Earth asteroids?

In 2013, a small asteroid exploded over the city of Chelyabinsk, Russia. That object was about 19 metres (62 feet) across, or about as big as a store. Objects of this size hit the Earth every 50 years or so.

66 million years ago, a much larger object hit the Earth, causing a massive extinction. 75 per cent of plant and animal species were lost, including, sadly, the dinosaurs. That object was about ten kilometres (six miles) across, and ten kilometres (six miles) is roughly the cruising altitude of a [Boeing] 747 jet. So the next time you're in an aeroplane, snag a window seat, look out and imagine a rock so enormous that resting on the ground it just grazes your wingtip. It's so wide that it takes your plane one full minute to fly past it. That's the size of the asteroid that hit the Earth.

It has only been within my lifetime that asteroids have been considered a credible threat to our planet. And since then, there's been a focused effort underway to discover and catalogue these objects. This is our responsibility. If we found a hazardous asteroid with significant early warning, we could nudge it out of the way. Unlike earthquakes, hurricanes or volcanic eruptions, an asteroid impact can be precisely predicted and prevented. What we need to do now is map near-Earth space. We must keep searching the sky.

Carrie Nugent is part of NASA's NEOWISE mission, currently searching for asteroids

© NASA/JPL ; Tobias Roetsch; Science History Institute; Olin College of Engineering; CFA;

HUNT FOR LIFE

Where is the best place to search for life in our Solar System?

As we move out into the Solar System, there's the tiny moon Enceladus. This is not in what we call the traditional habitable zone, this area around the Sun. This object should be ice over a silicate core.

Well, we believe because it has water and has had it for a significant period of time, and we believe it has hydrothermal vents with perhaps the right organic material, it is a place where life could exist. And not just microbial - maybe more complex because it's had time to evolve.

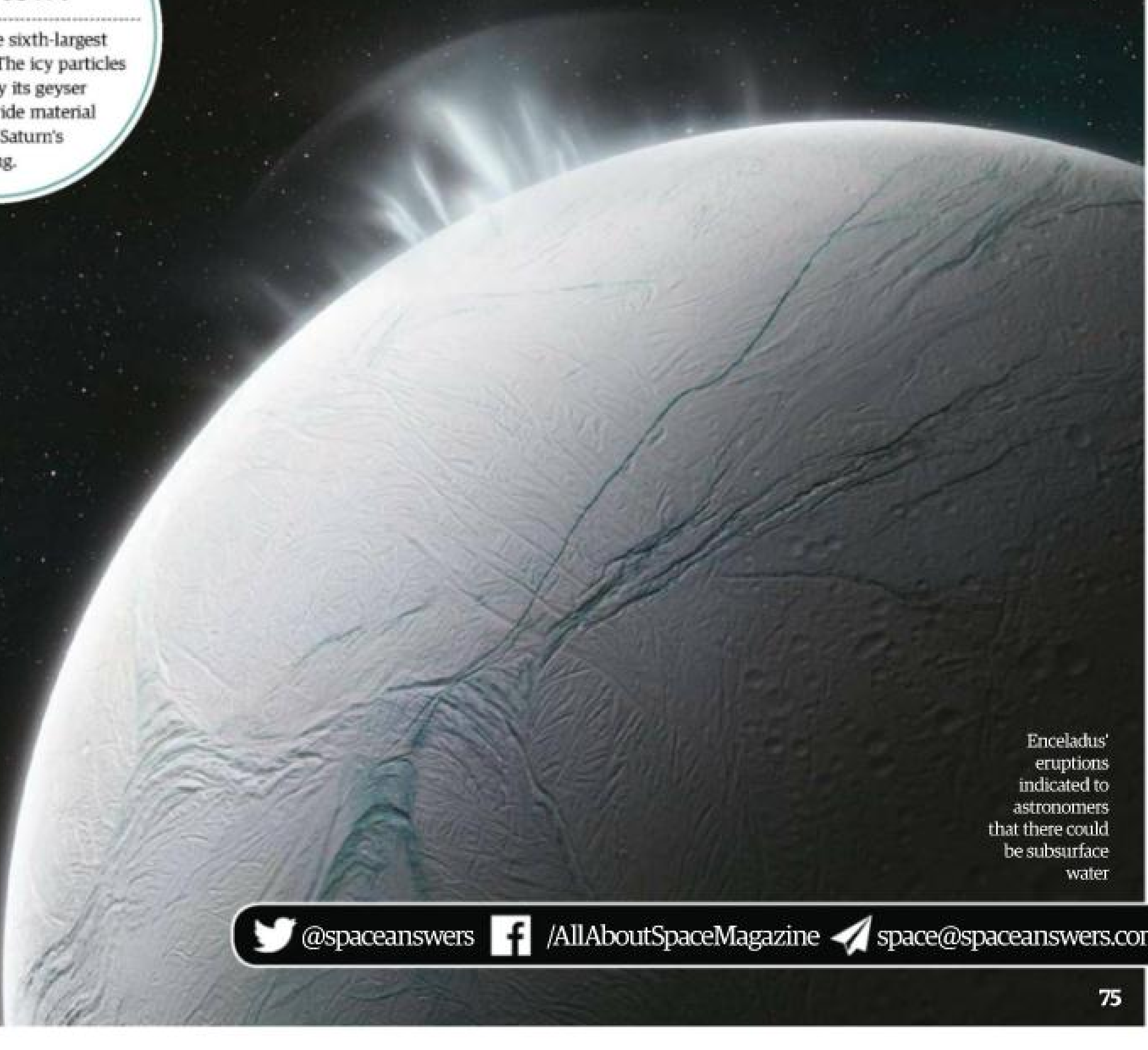
Another moon, very similar, is Europa. Galileo visited Jupiter's system in 1996 and made fabulous observations of Europa. Europa, we also know, has an under-the-ice-crust ocean. The Galileo mission told us that, but we never saw any plumes. But we didn't look for them.

Hubble, just a couple of years ago, observing Europa, saw plumes of water spraying from the cracks in the southern hemisphere, exactly like Enceladus. These moons, which are not in what we call a traditional habitable zone, that are out in the Solar System, have liquid water. And if there are organics there, there may be life.

James Green is NASA's chief scientist and has been with the organisation since 1980, contributing to many of NASA's most amazing missions

Did you know?

Enceladus is the sixth-largest Saturnian moon. The icy particles thrown out by its geyser eruptions provide material that feeds Saturn's E-ring.



Enceladus' eruptions indicated to astronomers that there could be subsurface water

STARGAZER

ESSENTIAL GUIDES AND ADVICE FOR AMATEUR ASTRONOMERS

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What's in the sky?

20 JUN
The Ophiuchids reach their peak of five meteors per hour

21 JUN
June solstice

23 JUN
The Lagoon Nebula (Messier 8) is well placed for observation in Sagittarius

© NASA, ESA

1 JUL
Globular cluster Messier 22 is well placed for observation in Sagittarius

© Roberto Mura

1 JUL
Open star cluster IC 4756 is well placed for observation in Serpens

2 JUL
Total solar eclipse visible from Argentina, Chile, Pitcairn Islands, Uruguay, Brazil, French Polynesia, Paraguay, Bolivia, Peru, Falkland Islands, Cook Islands, Ecuador, Kiribati and Colombia

4 JUL
The Earth is at its furthest point from the Sun

14 JUL
Dwarf planet Pluto reaches opposition in Sagittarius, glowing at magnitude 14.5

15 JUL
The Capricornids reach their peak of five meteors per hour

16 JUL
Conjunction between the Moon and Saturn in Sagittarius

Red light friendly
In order to preserve your night vision, you should read our observing guide under red light

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

24 JUN

Mercury is at greatest elongation east, shining brightly at magnitude 0.4 in Gemini

29 JUN

Open star cluster NGC 6633 is well placed for observation in Ophiuchus

© Astronomical Institute of the Charles University

2 JUL

Asteroid 18 Melpomene is well placed for observation in Scutum

© Roberto Mura

8 JUL

The Capricornids will reach their peak of five meteors per hour

9 JUL

Saturn is well placed for observation in the constellation Sagittarius at magnitude 0.1

13 JUL

Conjunction between the Moon and Jupiter in Ophiuchus

16 JUL

The Moon and Pluto make a close approach passing within 0°02' of each other in Sagittarius

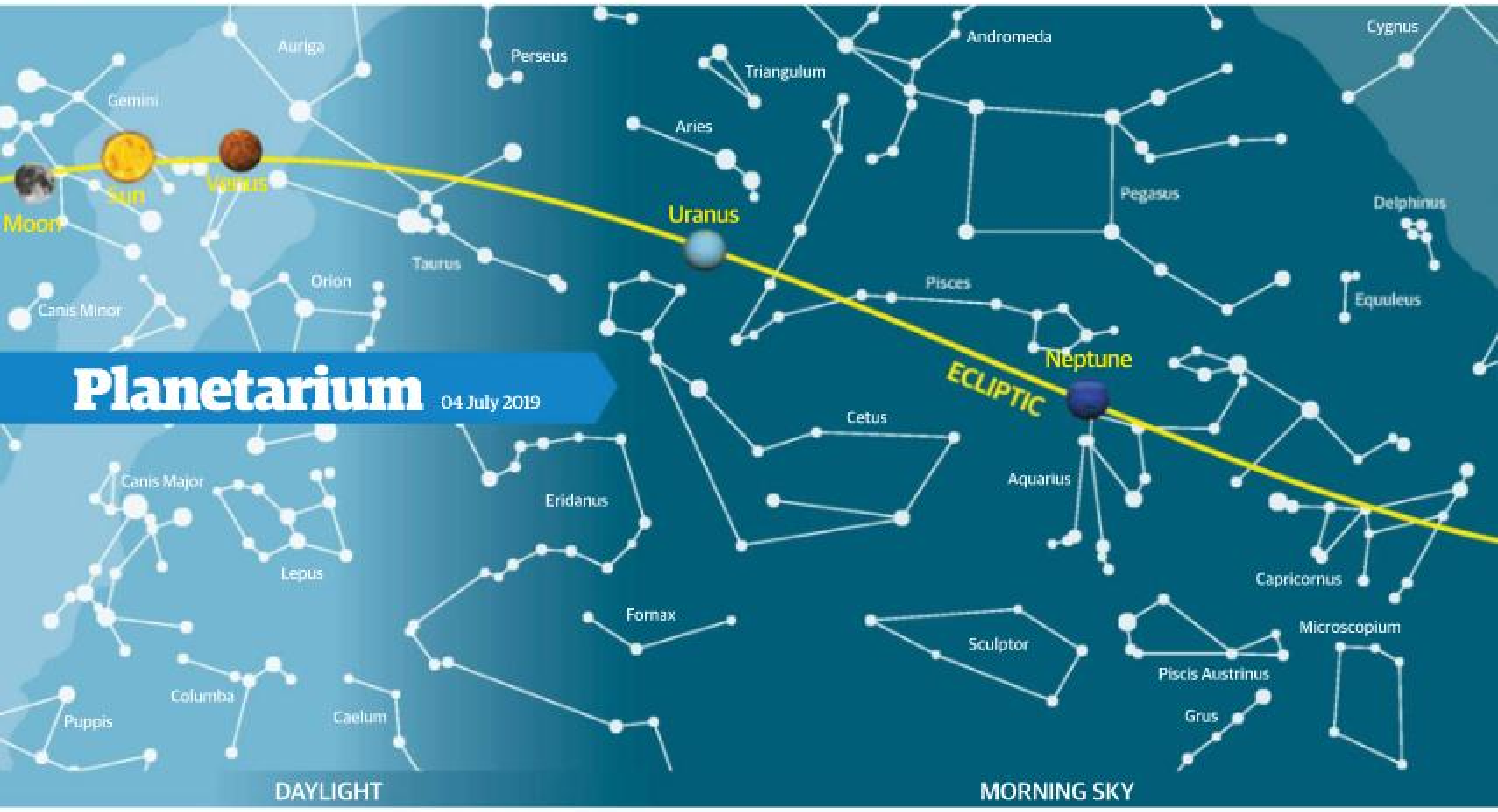
16 JUL

Partial lunar eclipse visible in Africa, Asia, Europe, South America and Australia

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

Planetarium

04 July 2019



Moon calendar

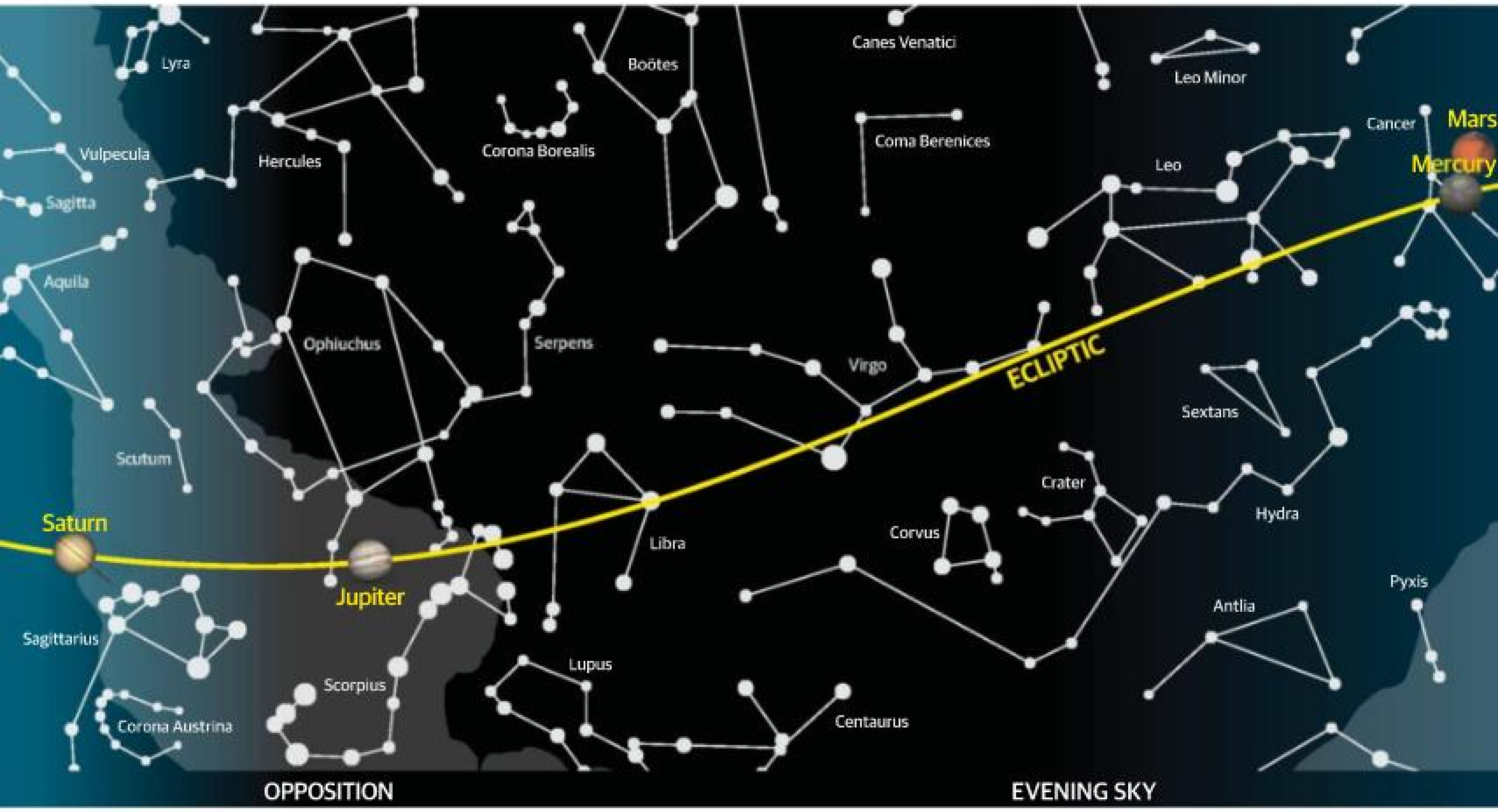
* The Moon does not pass the meridian on 15 July

			20 JUN 92.6% ◒ 07:31 ◓ 23:46	**21** JUN 86.5% ◒ 08:34 ◓ --:--	**22** JUN 79.1% ◓ 00:15 ◒ 09:39	**23** JUN 70.6% ◓ 00:39 ◒ 10:45
24 JUN 61.4% ◓ 01:00 ◒ 11:51	**25** JUN TQ 51.6% ◓ 01:18 ◒ 12:57	**26** JUN 41.7% ◓ 01:36 ◒ 14:04	**27** JUN 31.9% ◓ 01:55 ◒ 15:12	**28** JUN 22.6% ◓ 02:14 ◒ 16:23	**29** JUN 14.2% ◓ 02:37 ◒ 17:36	**30** JUN 7.3% ◓ 03:05 ◒ 18:51
1 JUL 2.5% ◓ 03:40 ◒ 20:03	**2** JUL NM 0.1% ◓ 04:25 ◒ 21:09	**3** JUL 0.7% ◓ 05:23 ◒ 22:06	**4** JUL 4.4% ◓ 06:33 ◒ 22:51	**5** JUL 10.9% ◓ 07:52 ◒ 23:27	**6** JUL 19.8% ◓ 09:14 ◒ 23:56	**7** JUL 30.3% ◓ 10:36 ◒ --:--
8 JUL 41.9% ◒ 00:20 ◓ 11:57	**9** JUL FQ 53.6% ◒ 00:43 ◓ 13:16	**10** JUL 64.9% ◒ 01:04 ◓ 14:34	**11** JUL 75.2% ◒ 01:26 ◓ 15:50	**12** JUL 84.0% ◒ 01:51 ◓ 17:04	**13** JUL 91.1% ◒ 02:19 ◓ 18:15	**14** JUL 96.2% ◒ 02:53 ◓ 19:20
15 JUL --:--*% ◒ 03:34 ◓ 20:18	**16** JUL FM 99.2% ◒ 04:24 ◓ 21:06	**17** JUL 100% ◒ 05:20 ◓ 21:45	**18** JUL 98.7% ◒ 06:22 ◓ 22:17			

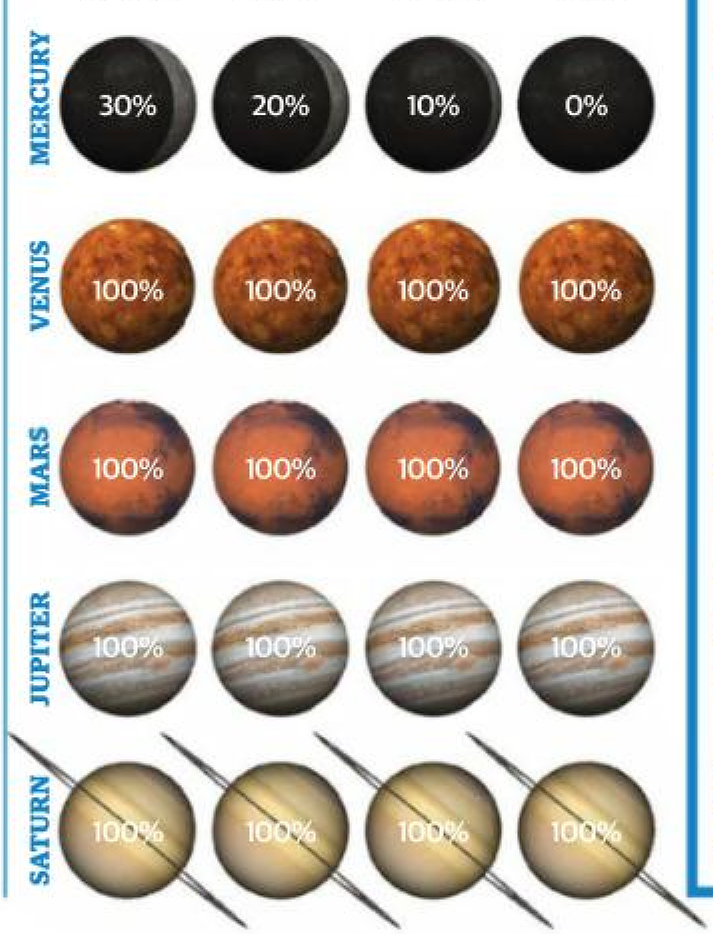
% Illumination
◓ Moonrise time
◒ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
LQ Last quarter

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage



	27 JUN	4 JUL	10 JUL	17 JUL
MERCURY	30%	20%	10%	0%
VENUS	100%	100%	100%	100%
MARS	100%	100%	100%	100%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

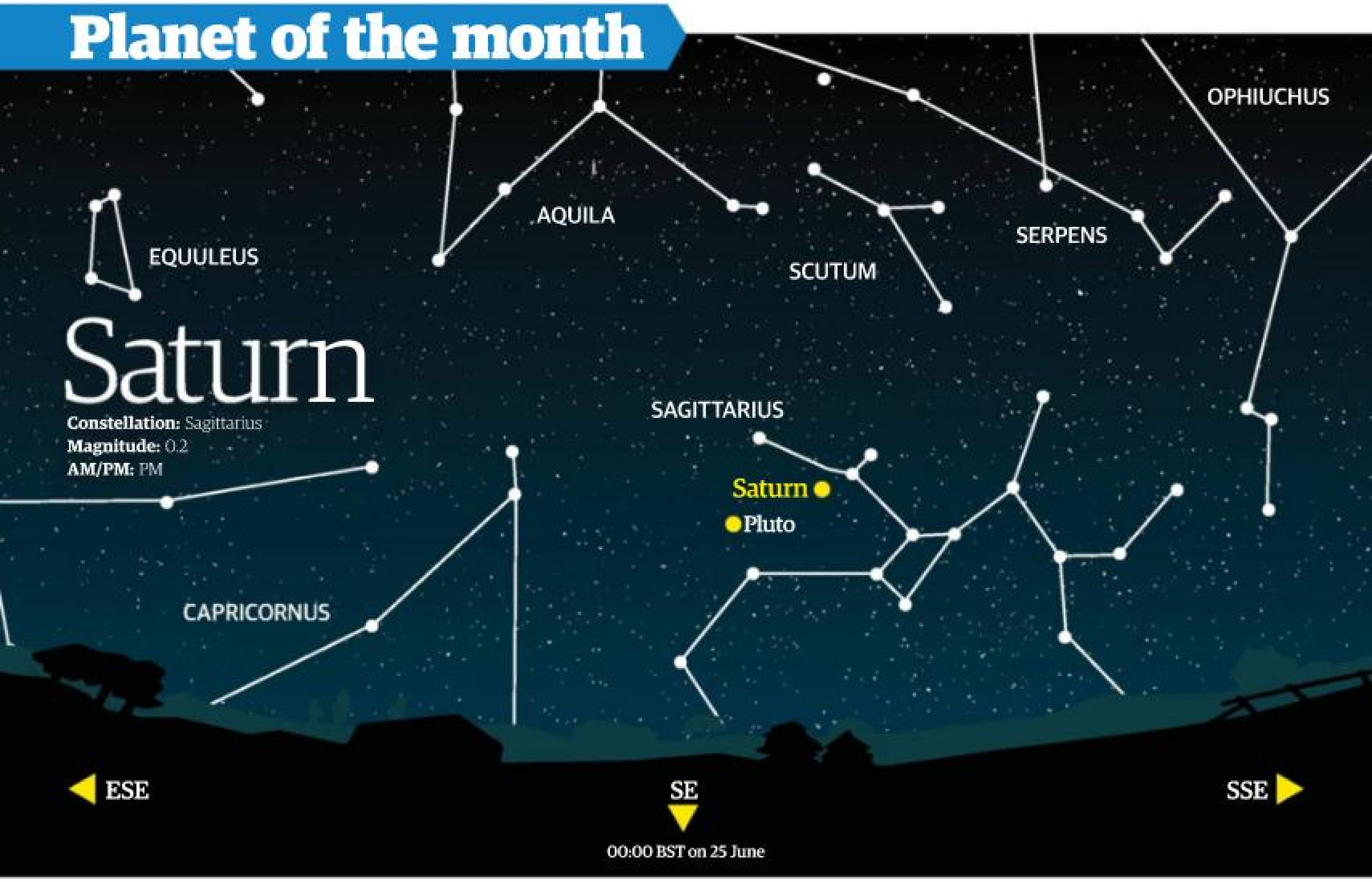
All rise and set times are given in BST

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	20 Jun	07h 39m 36s	+22° 42' 12"	Gemini	0.2	06:44	23:07
	27 Jun	08h 07m 33s	+20° 11' 23"	Cancer	0.7	07:02	22:50
	04 Jul	08h 21m 57s	+17° 44' 46"	Cancer	1.4	07:04	22:22
	10 Jul	08h 22m 19s	+16° 10' 07"	Cancer	2.4	06:50	21:49
	17 Jul	08h 09m 35s	+15° 24' 58"	Cancer	4.4	06:14	21:04
VENUS	20 Jun	04h 46m 56s	+21° 44' 34"	Taurus	-3.9	03:59	20:08
	27 Jun	05h 23m 37s	+22° 49' 28"	Taurus	-3.9	04:00	20:25
	04 Jul	06h 00m 48s	+23° 22' 26"	Gemini	-3.9	04:06	20:38
	10 Jul	06h 32m 51s	+23° 24' 09"	Gemini	-3.9	04:14	20:47
	17 Jul	07h 10m 10s	+22° 54' 48"	Gemini	-3.9	04:27	20:53
MARS	20 Jun	07h 36m 22s	+22° 46' 58"	Gemini	1.8	06:40	23:04
	27 Jun	07h 55m 22s	+21° 59' 40"	Gemini	1.8	06:37	22:50
	04 Jul	08h 14m 06s	+21° 04' 37"	Cancer	1.8	06:35	22:35
	10 Jul	08h 29m 58s	+20° 11' 38"	Cancer	1.8	06:33	22:22
	17 Jul	08h 48m 12s	+19° 03' 31"	Cancer	1.8	06:31	22:05
JUPITER	20 Jun	17h 08m 09s	-22° 20' 16"	Ophiuchus	-2.6	20:22	04:27
	27 Jun	17h 04m 31s	-22° 16' 41"	Ophiuchus	-2.6	19:51	03:56
	04 Jul	17h 01m 10s	-22° 13' 16"	Ophiuchus	-2.6	19:19	03:26
	10 Jul	16h 58m 36s	-22° 10' 39"	Ophiuchus	-2.5	18:53	03:00
	17 Jul	16h 56m 04s	-22° 08' 08"	Ophiuchus	-2.5	18:23	02:30
SATURN	20 Jun	19h 19m 18s	-21° 50' 18"	Sagittarius	0.1	22:30	06:41
	27 Jun	19h 17m 15s	-21° 54' 41"	Sagittarius	0.1	22:00	06:11
	04 Jul	19h 15m 06s	-21° 59' 10"	Sagittarius	0.1	21:31	05:41
	10 Jul	19h 13m 12s	-22° 03' 02"	Sagittarius	0.1	21:06	05:15
	17 Jul	19h 11m 00s	-22° 07' 27"	Sagittarius	0.1	20:37	04:45

This month's planets

Saturn is passed by a partial lunar eclipse this month, while other members of the Solar System are a challenge – even through a telescope

Planet of the month



00:00 BST on 25 June

Saturn

Constellation: Sagittarius
Magnitude: 0.2
AM/PM: PM

Some experienced sky-watchers and planet-spotters might be a bit puzzled as to why Saturn has been given our prestigious 'Planet of the Month' spot this month. After all, at magnitude 0.2 it's hardly going to blaze like a beacon in the sky. Although it will be an easy naked-eye object, at magnitude 0.2 it's not even as bright as Rigel, the second-brightest star in Orion. It will appear much fainter than Jupiter, which will be visible to Saturn's right and will look a lot brighter and much more striking. The most famous ringed planet is not particularly well-placed in the sky this month either; it will be visible low in the southeast as the sky darkens after sunset and will gain so little altitude after it rises that all through the evening it will scrape the roofs and treetops as it is slowly carried westwards by Earth's rotation. So why was it given our top spot?

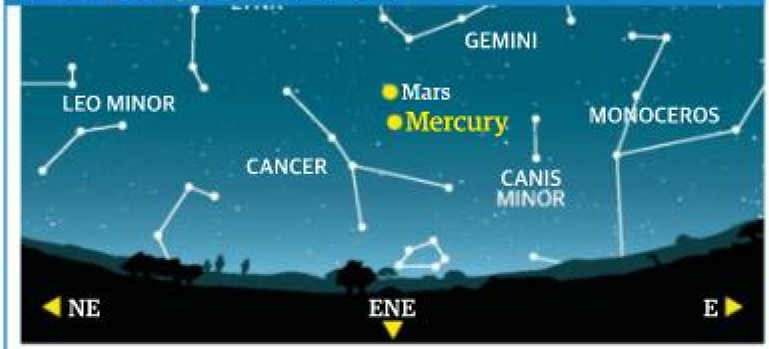
It's because Saturn is going to keep some very interesting company this month. For a start, through June and July Saturn is going to be shining to the upper left of one of the most famous asterisms of stars in the whole of the sky. Sagittarius is meant to represent an archer, and most likely resembled one to the ancient stargazers who named it all those centuries ago when its fainter stars gave it the outline of an archer in dark skies blissfully free of light pollution, but today its brightest stars are usually connected, join-the-dots fashion, into the shape of a teapot. Throughout summer Saturn will be found to the upper left of this teapot's handle, and in fact won't stray from it until we lose it later in the year.

In mid-July Saturn is going to photobomb a major astronomical event that will have sky-watchers looking up at the heavens from across a large area of our planet. On the evening of 16 July there will be a partial eclipse of the Moon, and as it is happening the Moon will be less than eight degrees away from Saturn, down to its lower left. So – weather permitting, of course – we'll be able to enjoy the lovely, rare sight of Saturn and a half-eclipsed Moon shining together in the summer sky.

The partial lunar eclipse will already be underway when the full Moon rises in the southeast. With the Sun setting directly opposite it in the sky, and a large, dark bite taken out of its upper left, the Moon's disc will look a lot like Pacman as it climbs up into the sky. By 22:45 the eclipse will be at its maximum, with around half the Moon's disc darkened by Earth's shadow. After that more and more of the bright disc will emerge from that shadow until the eclipse ends at midnight.

This month's planets

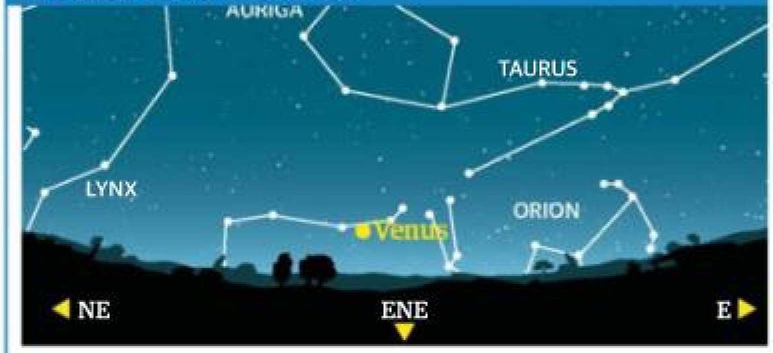
Mercury 09:00 BST on 1 July



Constellation: Gemini
Magnitude: 0.4
AM/PM: PM

This won't be a brilliant month for seeing the closest planet to the Sun, but if you're patient - and careful - you should manage it. Mercury is an evening object, already low in the northwest after sunset. You might need a pair of binoculars to pick it out against the sky, even as twilight is deepening.

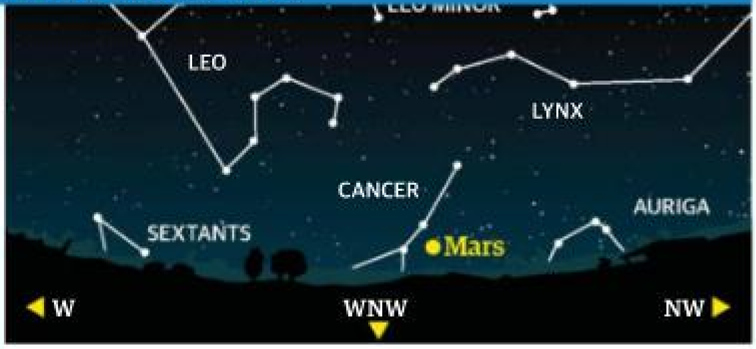
Venus 05:00 BST on 10 July



Constellation: Taurus
Magnitude: -3.9
AM/PM: AM

Venus is technically a morning object, and you would think from looking at that impressive magnitude of -3.9 that it would be blazing in the sky, but that's rather misleading: by mid-June Venus is so close to the Sun in the sky that it will be too close for all but the most experienced planetary observers to see.

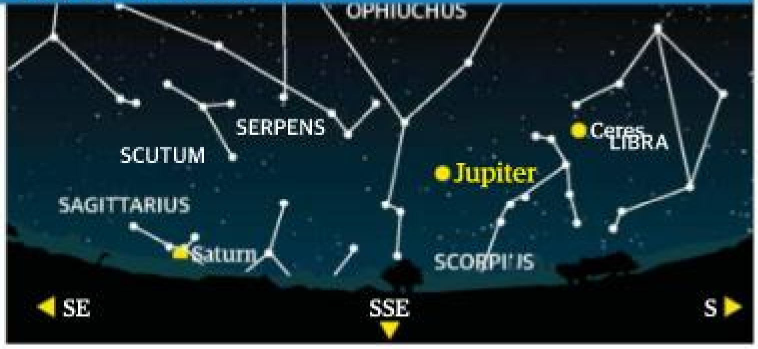
Mars 21:30 BST on 10 July



Constellation: Gemini
Magnitude: 1.8
AM/PM: PM

Mars will be a 'challenging' object this month to say the least. For a start it will already be very low in the northeastern sky after sunset. Shining - if that's the right word to use - at just magnitude 1.8, barely brighter than Polaris, the Pole Star, it will be too faint for most people to see with the naked eye.

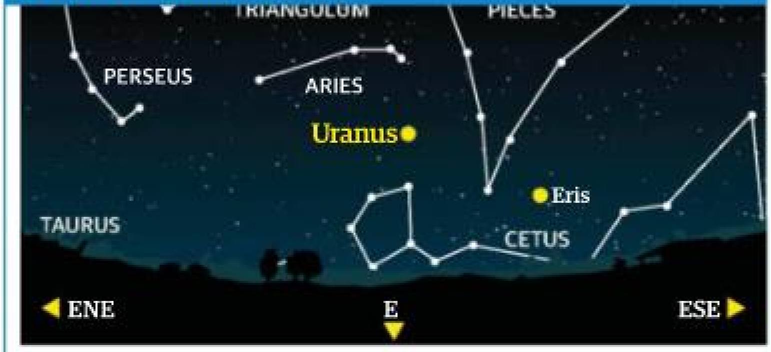
Jupiter 22:00 BST on 10 July



Constellation: Ophiuchus
Magnitude: -2.6
AM/PM: PM

The largest planet in our Solar System is visible as a blue-white 'star' low in the southeast as soon as the sky starts to darken after sunset, and by midnight is a very striking object above the southern horizon, brighter than any other stars or objects around it, including nearby ruddy-hued Antares, brightest star of Scorpius.

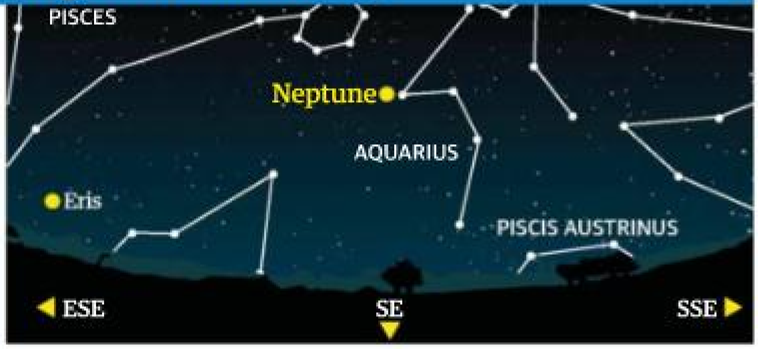
Uranus 03:00 BST on 15 July



Constellation: Aries
Magnitude: 5.9
AM/PM: AM

Uranus will not be rising in the east until around 02:00, when the sky is already starting to lighten again after its short spell of relative darkness. You'll definitely need at least a pair of binoculars to see it, and even then it will just look like a faint star before the approach of dawn washes its faint light from the sky.

Neptune 03:00 BST on 15 July



Constellation: Aquarius
Magnitude: 7.9
AM/PM: AM

Neptune is much too faint to see with the naked eye. A telescope will reveal its small disc, but you'll need a lot of magnification. If you really want to track it down, in mid-June Neptune will rise in the east at around 01:00, and by mid-July will be rising an hour earlier, but its faint light will be lost as soon as the sky begins to brighten.

Top tip!

Don't expect to see Apollo 11's flag and footprints through your telescope from your garden. Not even the Hubble Space Telescope can do that!

Moon tour

The Sea of Tranquillity

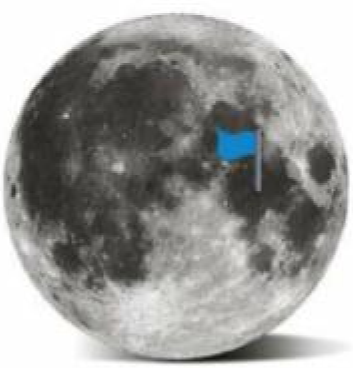
Celebrate Apollo 11's 50th anniversary by finding the Eagle's landing site in the most famous sea on the Moon

It seems almost impossible to believe it was so long ago, but as this issue of **All About Space** hits the shelves it will be half a century since the first humans walked on the Moon. 50 years ago in July 1969, with the world watching and with their crewmate Michael Collins orbiting the Moon high above them, Neil Armstrong and Buzz Aldrin skillfully guided the Apollo 11 lunar module, Eagle, down to the surface of the Moon. After a tense few last moments of flying low over a boulder field in search of a safe landing site they finally set their spindly looking spacecraft down near the southern 'shore' of one of the Moon's mare, or seas, which are of course not seas like those we have here on Earth, but are vast plains of cold, ancient, frozen lava. This sea is now the most famous feature on the Moon - the Sea of Tranquillity.

Named and drawn on their first Moon maps in 1651 by early lunar cartographers Grimaldi and Riccioli, the Sea of Tranquillity is a smooth, dark plain more than 870 kilometres (451 miles) across. Ringed with mountains and hills, peppered with many craters and etched with claw-mark-like valleys and rilles, the roughly oval-shaped Mare Tranquillitatis lies on the right side of the Moon's Earth-facing side, to the south of the larger and rounder Sea of Serenity and to the north of the smaller seas of Mare Nectaris and Mare Fecunditatis. In contrast to those seas around it, which appear dark and black-grey when photographed, high-resolution images of Mare Tranquillitatis show it has a strong blue tint, which we now know is the result of its basaltic lava having a higher metal content than that of its neighbours.

Apollo 11's Eagle lunar module was not the first spacecraft to reach this silent, still sea. In February 1965 the Ranger 8 probe crashed into it and was destroyed, but not before sending back over 7,000 priceless images of the Moon in the last 23 minutes of its mission. In September 1967, more than a year before the crew of Apollo 8 became the first human beings to reach the Moon, the Surveyor 5 probe set down on the Sea of Tranquility, just 25 kilometres (16 miles) away from the area where the Eagle would land less than two years later.

As the world marks the 50th anniversary of Eagle's landing and looks back at the amazing achievements of the whole Apollo program, what better way is there to join in with the celebrations than to actually look at the Sea of Tranquillity on the Moon on the date of the anniversary? Luckily, finding it isn't hard at all. Just look at the Moon on any night between first quarter phase and just after full Moon and you'll be able to spot it as a dark patch in the centre-right area of the Moon's mottled face.

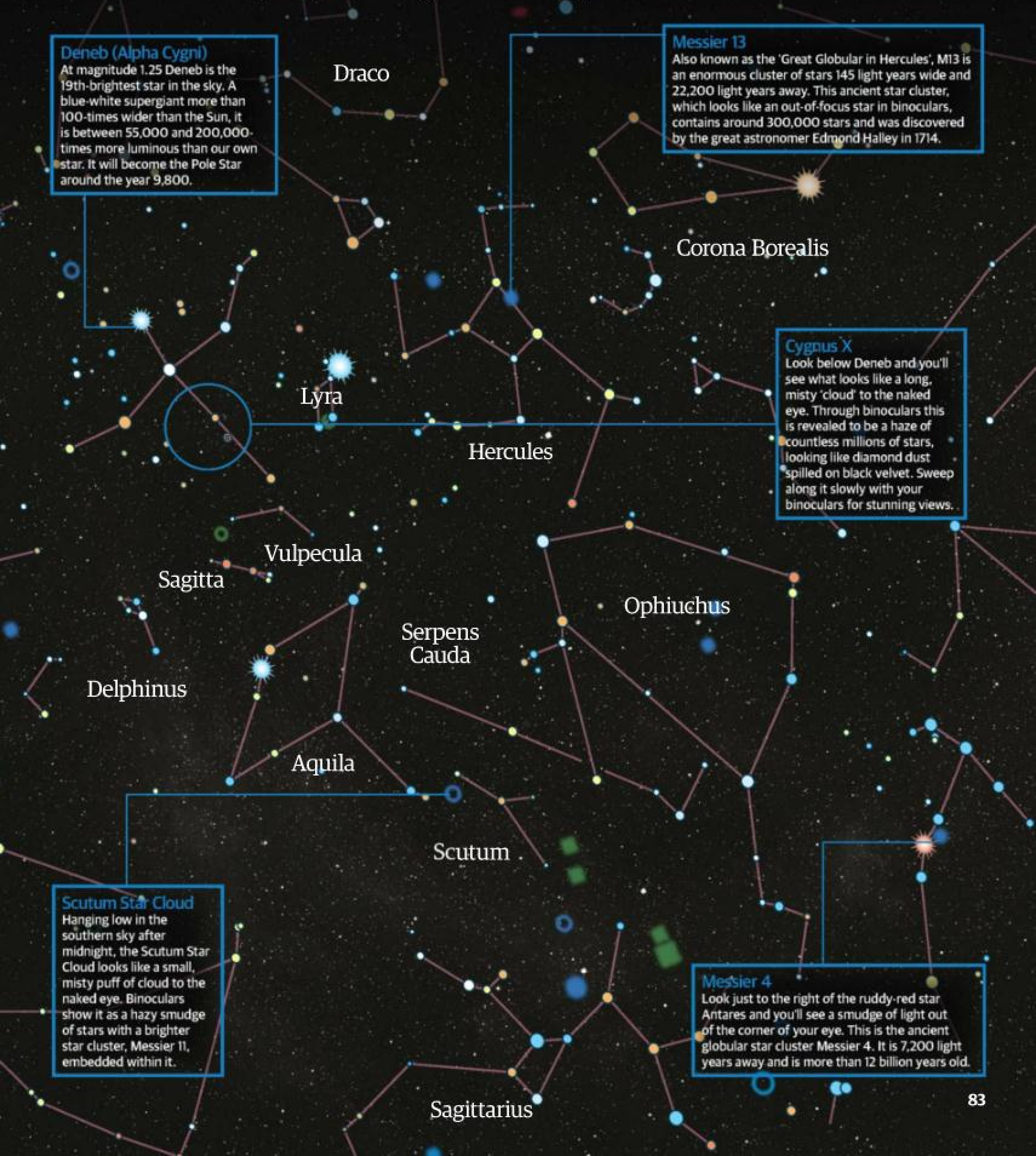


At the start of our observing period the Moon will be waning, and Mare Tranquillitatis will be half-illuminated. It will vanish from view on 24 June as the terminator sweeps over it, plunging it into darkness, and won't reappear until around 6 July when the Moon is a waxing crescent again. On 20 July, the actual date of the anniversary, the Sea of Tranquillity - and the Apollo 11 landing site - will be fully illuminated and visible all night. You won't see footprints through your binoculars or telescope, and you certainly won't see the 'Stars and Stripes' flag that blew over as Eagle lifted off the Moon, but you will see the historic area of the Moon where history was made half a century ago. If you have a telescope you will be able to zoom in on the landing area and imagine you were standing inside Eagle behind Neil Armstrong and Buzz Aldrin as they guided their fragile spacecraft down to Tranquillity Base, where, watched by millions staring at flickering black-and-white TV screens all around the world, Armstrong would take his "one small step for man, one giant leap for mankind".

© Gregory H. Revera

Naked eye & binocular targets

The summer Milky Way offers a plethora of targets



Deneb (Alpha Cygni)
At magnitude 1.25 Deneb is the 19th-brightest star in the sky. A blue-white supergiant more than 100-times wider than the Sun, it is between 55,000 and 200,000-times more luminous than our own star. It will become the Pole Star around the year 9,800.

Messier 13
Also known as the 'Great Globular in Hercules', M13 is an enormous cluster of stars 145 light years wide and 22,200 light years away. This ancient star cluster, which looks like an out-of-focus star in binoculars, contains around 300,000 stars and was discovered by the great astronomer Edmond Halley in 1714.

Cygnus X
Look below Deneb and you'll see what looks like a long, misty 'cloud' to the naked eye. Through binoculars this is revealed to be a haze of countless millions of stars, looking like diamond dust spilled on black velvet. Sweep along it slowly with your binoculars for stunning views.

Scutum Star Cloud
Hanging low in the southern sky after midnight, the Scutum Star Cloud looks like a small, misty puff of cloud to the naked eye. Binoculars show it as a hazy smudge of stars with a brighter star cluster, Messier 11, embedded within it.

Messier 4
Look just to the right of the ruddy-red star Antares and you'll see a smudge of light out of the corner of your eye. This is the ancient globular star cluster Messier 4. It is 7,200 light years away and is more than 12 billion years old.

How to...

Observe noctilucent clouds

Just because it doesn't really get dark during the summer months doesn't mean there's nothing to look at in the night sky. After midnight you might see a beautiful sight low in the north

You'll need:

- ✔ Dark observing site with no light pollution
- ✔ Clear view to the north with a low horizon
- ✔ DSLR camera and tripod (optional)
- ✔ Binoculars (optional)

It's one of the greatest frustrations of being an amateur astronomer that in June and July, when the Milky Way would be at its best, the night sky never gets dark enough to see it properly. The Sun sets late and rises again so early through the summer months that twilight just lingers and never goes away. Even at midnight only the brightest stars and planets can be seen. But that doesn't mean there's nothing to see. The summer months are the only time we can see one of nature's most beautiful sights - a phenomenon many devoted observers consider to be just as beautiful as the more famous northern lights. Summer is the season for hunting noctilucent clouds, or 'NLC'.

Noctilucent clouds are clouds that shine - 'lucent' - at night -'nocti'. However, they are very different to the puffy, pillow-white cumulus or wispy cirrus clouds we see in the daytime. Those clouds are made of water droplets, and are quite low down in the atmosphere. NLC are much higher, on the edge of space, and composed of dusty ice crystals.

It's because they are so high that we can see NLC: when the Sun has dropped below our horizon down here on the ground its rays still illuminate NLC high up in the atmosphere, lighting them up.

NLC look like nothing else in astronomy. Always seen in the northern part of the sky, they resemble streamers and tendrils of silvery blue light, almost like a special effect from a science-fiction film. No two displays are the same. Some are modest, with faint NLC just hugging the horizon, barely bright enough to be seen with the naked eye. Other displays can be outrageously bright, painting the whole of the northern sky - from west to east and halfway to the zenith - with a stunning show of blue, silver and even gold-hued whorls, swirls and curls. A display like this can last all night and still be going strong as dawn breaks.

> "The summer months are the only time we can see one of nature's most beautiful sights"

Tips & tricks

Location, location, location
Bright displays of NLC can be seen from anywhere with a view north, but you'll see much more if your northern horizon is low and flat.

A treat for the eyes
You don't need any special equipment to observe NLC. However, binoculars will show you beautiful fine structures and detail.

Use social media
Many observers post NLC alerts on social media, so following them on Twitter and Facebook will help you see displays.

Be patient
NLC displays often die down to nothing, and it's tempting to then give up and go home. Don't. Many displays return much bigger and brighter than before!

Capturing a rare phenomenon

The activity is difficult to predict - here's how to make the most of their appearance

Unlike auroral activity, NLC activity is very hard to predict. It's possible to get a hint that something might happen on any given night by looking at the conditions in the upper atmosphere. Radar scans can show activity and north-facing webcams can too, but observing NLC is one of the few remaining areas of amateur astronomy where you have to actually drag yourself off the sofa and go and have a look!

Send your photos to
space@spaceanswers.com

© Google Maps

1 **Get the best location**
You'll see more NLC displays from somewhere with a clear view north, looking towards a low, flat horizon.

2 **Look to the north**
Start to look for NLC activity low in the north around midnight on clear June and July nights. Be prepared to be out all night.

3 **Check out social media**
Monitoring social media for NLC activity alerts will stop you from missing a beautiful display visible from where you live.

4 **Look for streaks above the horizon**
NLC displays often start as faint, wispy gold streaks very low above the northern horizon. Binoculars will help you spot them.

5 **Look out for brightening**
Don't give up on a display if it begins to fade - it might blossom and burst into something spectacular filling half the sky!

6 **Capture with a DSLR**
Use a DSLR camera on a tripod with a wide-angle lens to photograph NLC displays. Take exposures several seconds long.

Lagoon Nebula (Messier 8)

Deep sky challenge

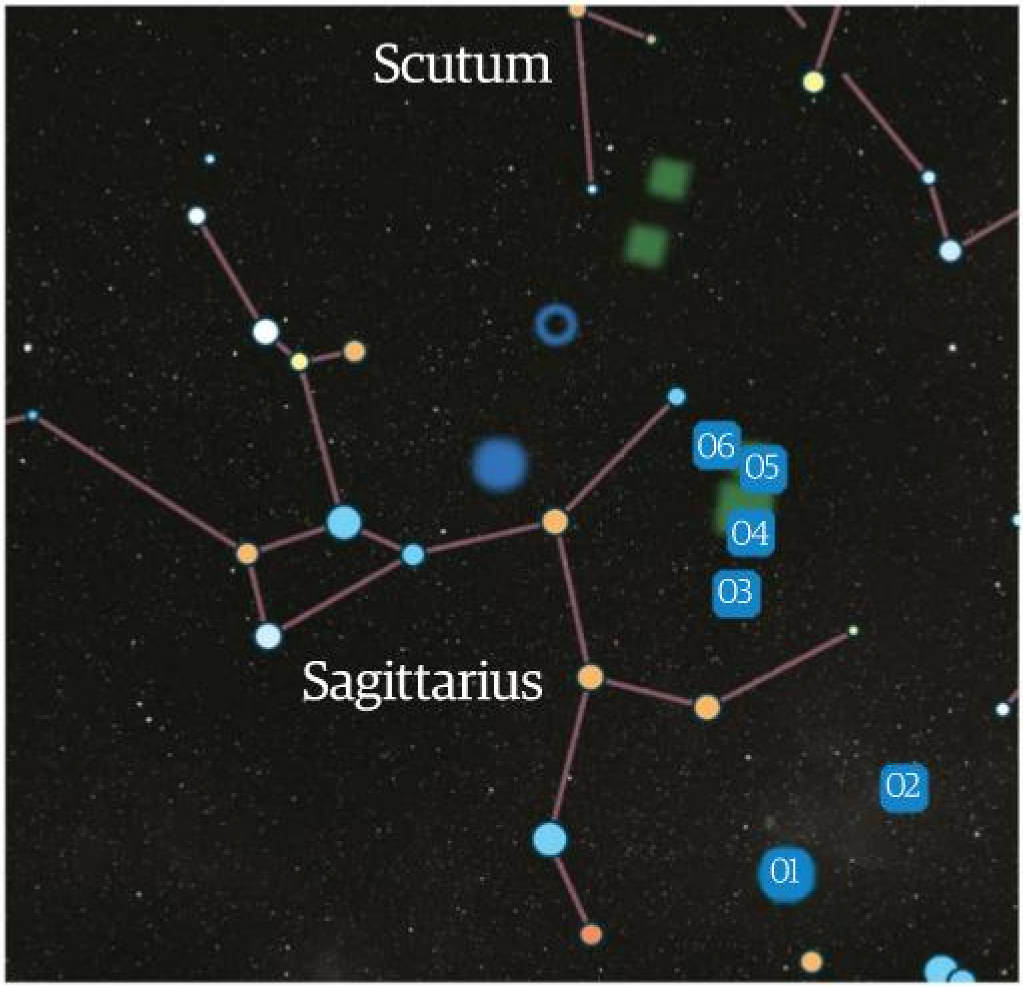
Stellar treasures of the Archer and Scorpion

Summer skies are stuffed full of amazing objects for your telescope – if you're prepared to stay up late

Summer in mid-northern latitudes gives us short nights which are never truly dark, which can wreak havoc on your viewing plans. However, they are dark enough to see some real celestial wonders. The Milky Way arcs almost from north to south at this time and brings with it all kinds of deep-sky gems, including open star clusters, globular star clusters and nebulae on which to feast your eyes.

Down near the southern horizon you will find the constellations of Scorpius and Sagittarius, which are packed with many such objects. For example there is open star cluster Messier 7 – this object can be challenging for Northern Hemisphere observers as it is so close to the horizon during this time of the year. On the other hand the exquisite Eagle Nebula, also known as Messier 16, is much more straight-forward to spot. Take a tour of just a few of the glorious objects within the borders of the Archer and the Scorpion for almost any size of telescope – they'll be worth staying up for!

NGC 6553



1 Ptolemy's Cluster (Messier 7)

A treat through a telescope. Sitting close to the 'stinger' of Scorpius, it is a challenging object for observers in northern latitudes.

2 Butterfly Cluster (Messier 6)

This is another great cluster for a small telescope. At around 100 million years old, the majority of the stars within this open cluster are hot, young, blue stars.

3 NGC 6553

This is a very loose globular star cluster. Packed with stars of magnitude 20 or dimmer, you will require a telescope with a large aperture to observe it effectively.

4 Lagoon Nebula (Messier 8)

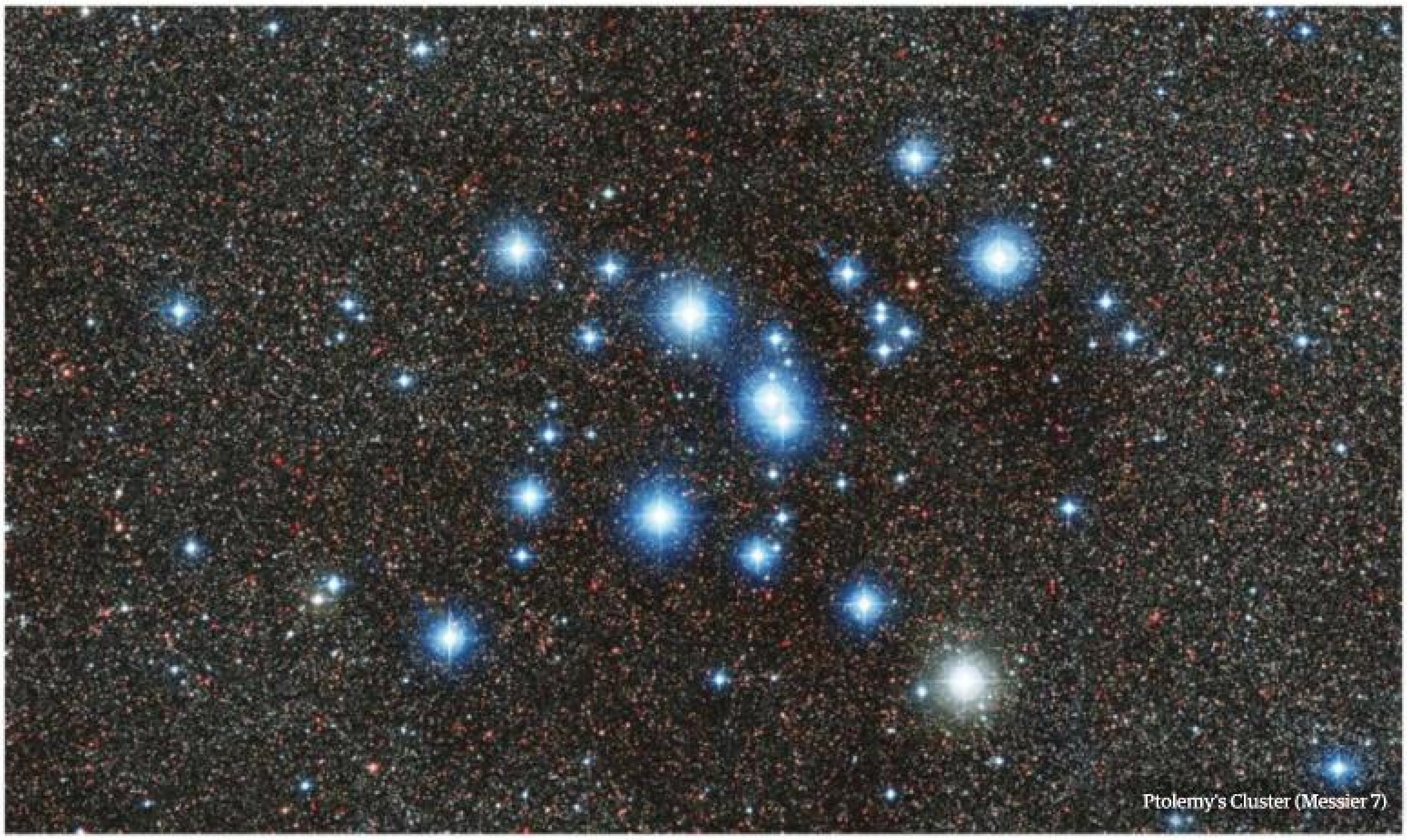
A small telescope at low power will see a faint oval patch of light with a definite core. The nebula is currently undergoing a period of active star formation. The group covers roughly 14 arcminutes.

5 Trifid Nebula (Messier 20)

Messier 20 consists of an emission nebula, a dark nebula and a reflection and an open cluster. The nebula is quite bright, with a magnitude of 9.0, making it a good target for small telescopes.

6 Messier 21

Tightly packed, this open cluster is best seen at medium power through a larger aperture scope. Messier 21 consists mainly of small, faint stars but it's also home to a few blue giants.



Ptolemy's Cluster (Messier 7)

© Wil Tirion; NASA; ESO;

The Northern Hemisphere

Bright- to faint-magnitude targets are on offer this July for astronomers armed with the right equipment

The constellations of Lyra, Aquila, Hercules, Sagittarius, Scorpius and Ophiuchus are in easy reach this month. What's more, these star patterns are packed with night-sky objects. Fans of tight-knit globular star clusters should turn their attention to Ophiuchus and Hercules, where they will be rewarded with sights of stellar-rich Messier 10, Messier 12, Messier 13, Messier 14 and Messier 92. Meanwhile astrophotographers will get great enjoyment from the binary star system Rho Ophiuchi in Ophiuchus, which is surrounded with a red emission nebula and very impressive light- and dark-brown dust lanes. Cygnus is another goldmine, with the Veil Nebula, Fireworks Galaxy and the Crescent Nebula being excellent choices for observation in particular.

Using the sky chart

This chart is for use at 10pm (BST) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

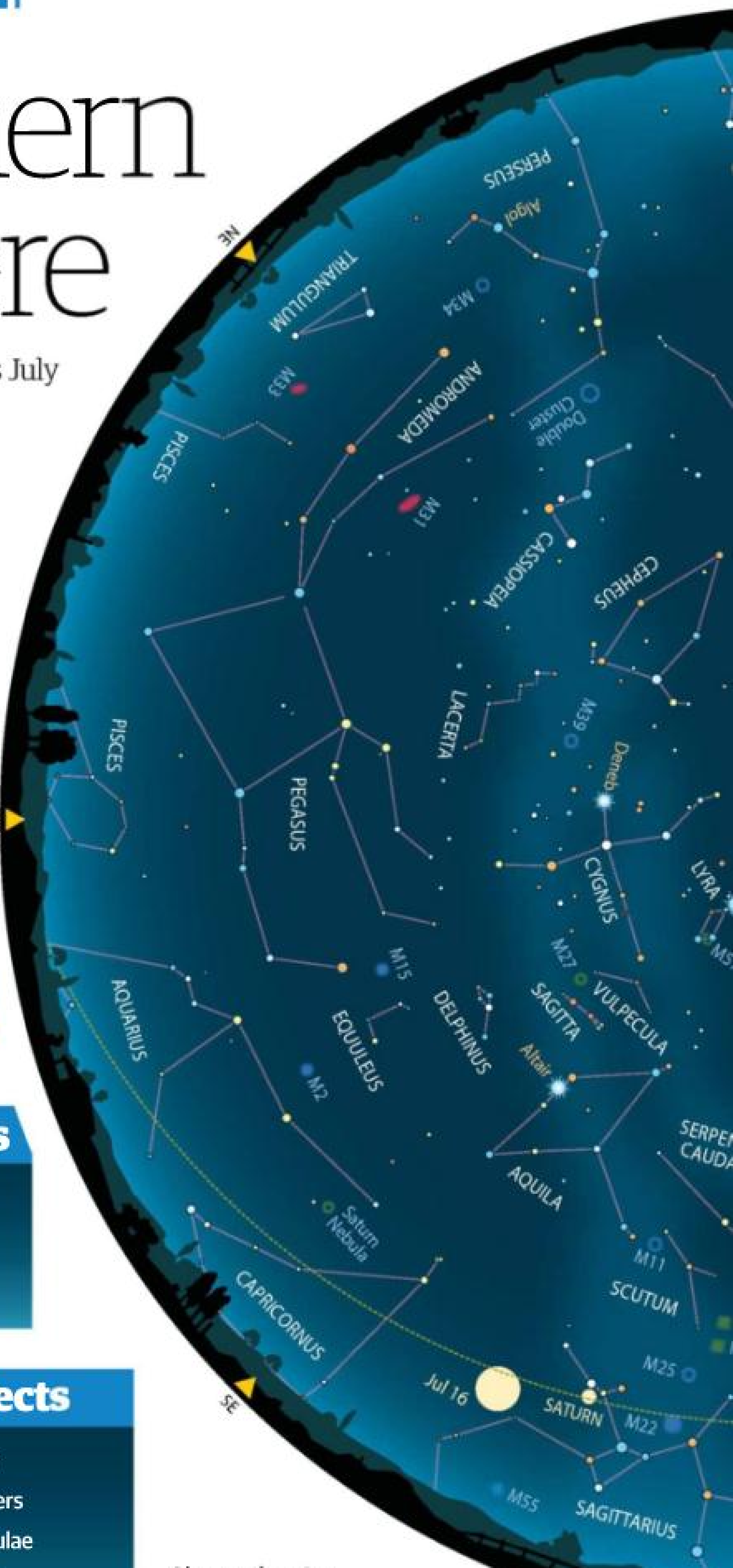
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

Spectral types

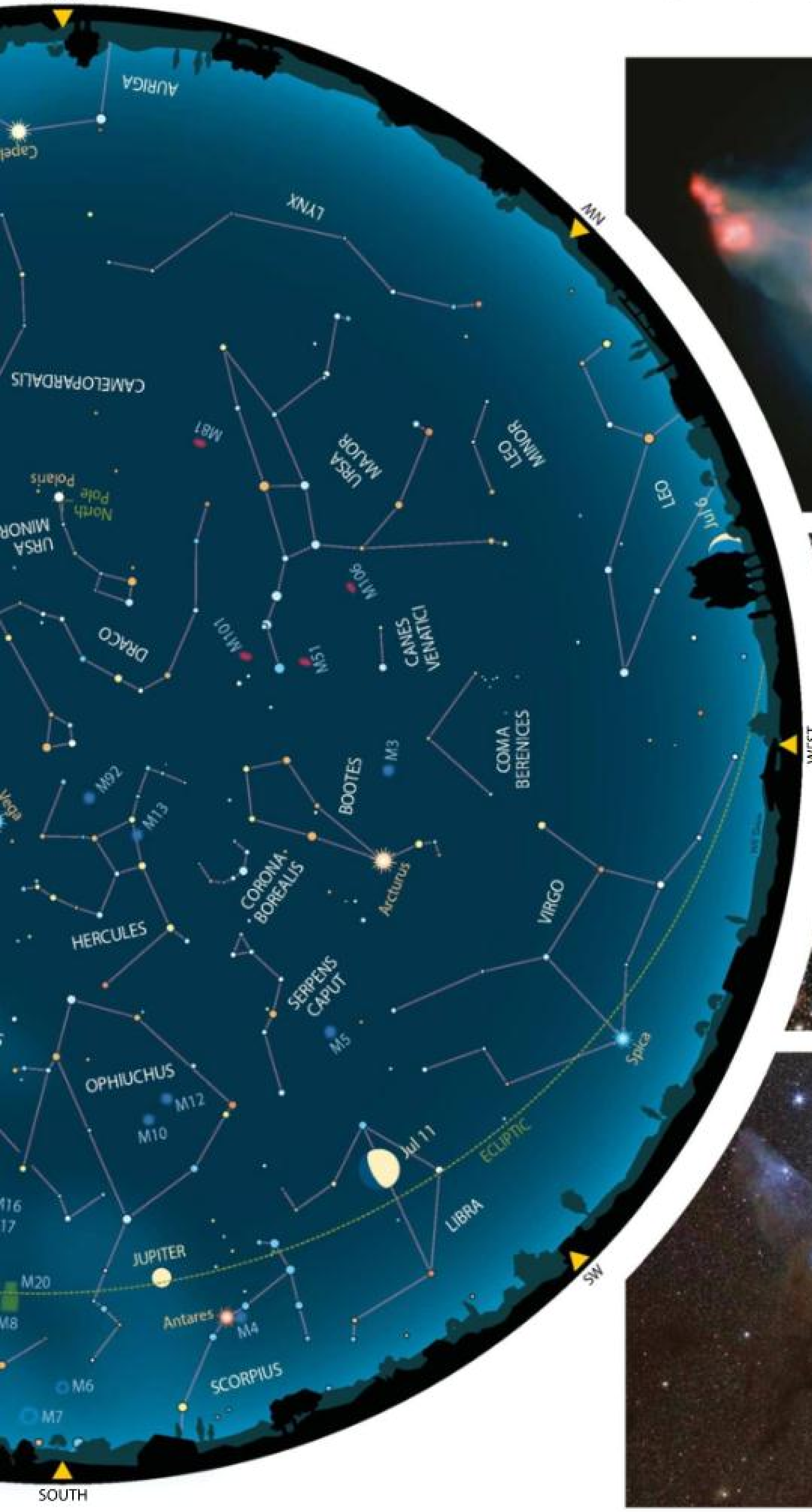
O-B	G
A	K
F	M

Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



Observer's note: The night sky as it appears on 16 July 2019 at approximately 10pm (BST).



Saturn Nebula (NGC 7009)

Messier 13

Rho Ophiuchi cloud complex

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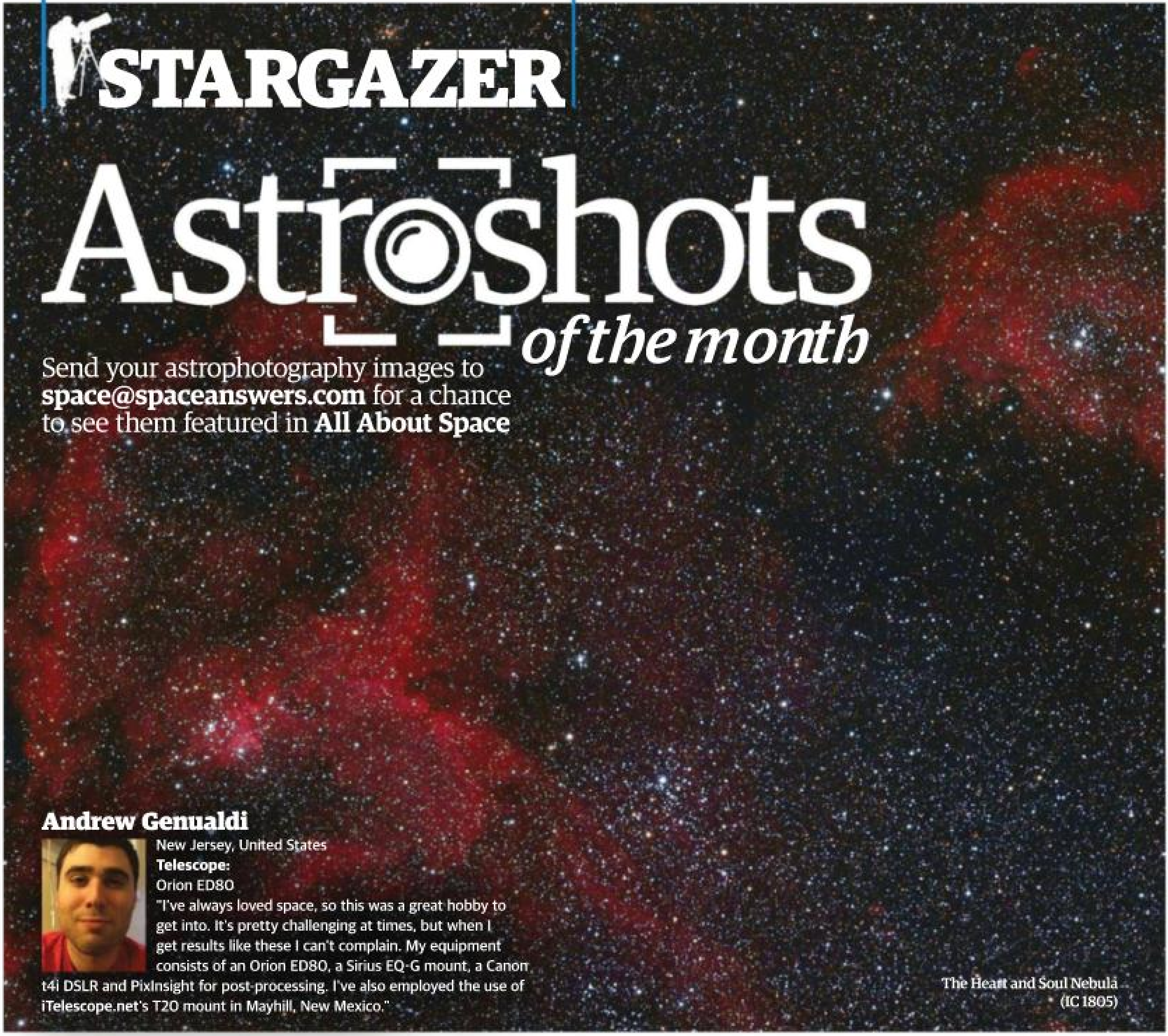
Astroshots of the month

Send your astrophotography images to **space@spaceanswers.com** for a chance to see them featured in **All About Space**

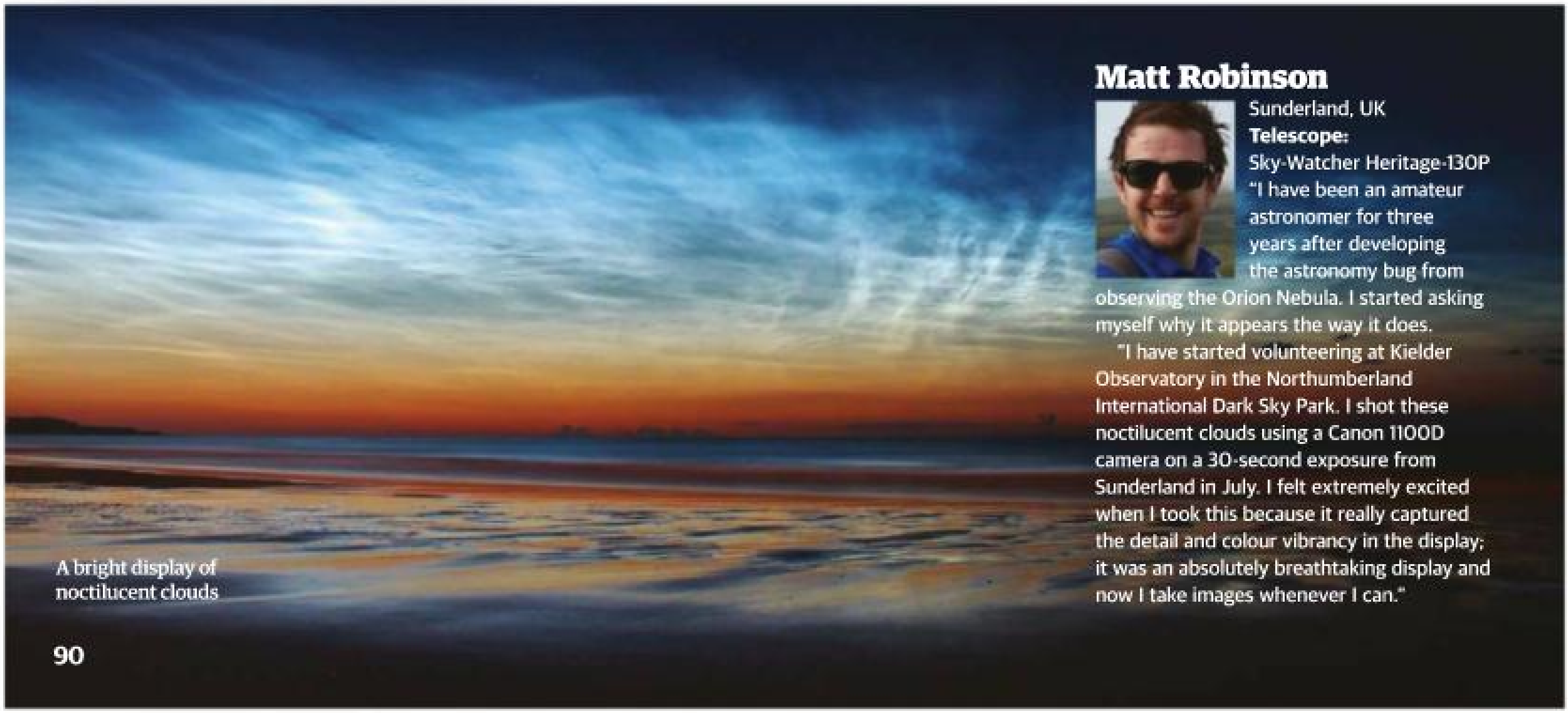


Andrew Genualdi

New Jersey, United States
Telescope:
Orion ED80

"I've always loved space, so this was a great hobby to get into. It's pretty challenging at times, but when I get results like these I can't complain. My equipment consists of an Orion ED80, a Sirius EQ-G mount, a Canon t4i DSLR and PixInsight for post-processing. I've also employed the use of iTelescope.net's T20 mount in Mayhill, New Mexico."

The Heart and Soul Nebula (IC 1805)



A bright display of noctilucent clouds

Matt Robinson

Sunderland, UK
Telescope:
Sky-Watcher Heritage-130P

"I have been an amateur astronomer for three years after developing the astronomy bug from observing the Orion Nebula. I started asking myself why it appears the way it does.

"I have started volunteering at Kielder Observatory in the Northumberland International Dark Sky Park. I shot these noctilucent clouds using a Canon 1100D camera on a 30-second exposure from Sunderland in July. I felt extremely excited when I took this because it really captured the detail and colour vibrancy in the display; it was an absolutely breathtaking display and now I take images whenever I can."

Andromeda Galaxy (M31)

Andy Milner

King's Lyn, Norfolk
Telescope:
Sky-Watcher Explorer-200P Maksutov-Cassegrain

"I've always been intrigued by the night sky, and decided it was about time I got a telescope. It's been a great journey so far – I've made many friends and gained a huge amount of experience. I am a committee member of my local astronomy society and help administrate online astronomy forums such as Astronomy For Beginners (A4B).

"My main passion is astrophotography, and I have built up a large range of accessories. These images are either taken with my Canon 1100D DSLR, or with a high-FPS planetary camera."

Comet Lovejoy (C/2014 Q2)

The Pleiades (M45)

Send your photos to... @spaceanswers @ space@spaceanswers.com

Vixen BT81S-A

This advanced binocular-design instrument allows you to set your sights on the night sky – using both eyes

Telescope advice

Cost: £799/$1,019
From: Opticron
Type: Binocular telescope
Aperture: 3.19"
Focal length: 18.90"

Best for...

- Intermediate
- Large budget
- Planetary viewing
- Lunar viewing
- Bright deep-sky objects

Granted, the Vixen BT81S-A doesn't look like your standard telescope. In our view though, having two tubes to observe the universe is a massive plus, given that this telescope binocular doesn't require you to hunch over a single eyepiece to peer at the cosmos. With an aperture of just over three inches we have the observing capabilities of a small telescope, giving us the option to gaze at a variety of targets from Solar System objects to the brighter deep-sky targets such as nebulae and star clusters.

Unpacking the BT81S-A, we were immediately impressed with its quality, which is extremely sturdy and boasts resilience for many observing sessions. For the price, this binocular telescope doesn't come with much in the way of accessories. Buyers are supplied with two high-quality 25mm Vixen NLV series eyepieces to get them started with touring the night sky, but what's really needed – due to its 4.1 kilogram weight – is a tripod to achieve steady viewing. This essential piece of kit, along with a finderscope, needs to be purchased separately to get the most out of the BT81S-A. Thanks to the presence of a versatile Vixen dovetail fitting, the binocular telescope can accept either an equatorial or an alt-azimuth mount. We also noted the carry handle, found at the top of the binocular telescope barrels, which improved the instrument's portability, allowing us to transport it to a wide variety of dark-site locations. It also proved to be invaluable for attaching the BT81S-A to a tripod as well as unpacking and packing the device away after a night of observing.

Attaching the binocular telescope to an in-house equatorial mount, it wasn't long before we were comfortably touring the night sky. Added comfort was had due to the 45-degree angle of the versatile 1.25" eyepiece holders, which are orientated in such a way that we didn't need to stoop down – as you would with a telescope – in order to study the night sky. The eyepiece holders employ a push-fit mechanism with a holding screw to keep the eyepieces secure. Given the excellent design of this device, we did expect more in the way of holding the eyepieces in place, but since they were secure, with no slippage or wobbling, this is really just a minor point.

The BT81S-A provides a wide field of view of about 3.5 degrees when used with a pair of 40mm eyepieces, which we plugged into the eyepiece holders. Given the generosity of the field of view, we got stuck into observing the Messier 53, a tight ball of light with its member stars appearing as steady, bright points in Coma Berenices. Meanwhile, Messier 84 appeared as a ball of cotton wool alongside other elliptical galaxies in the constellation of Virgo. Viewing conditions were not favourable during our initial review of the BT81S-A as thick clouds took over the night sky, and as a result we had to wait to take in views of the Moon and Venus.

That evening arrived soon enough, and what we saw as soon as we put our eyes to the eyepieces was beyond spectacular. The Moon fitted comfortably in our field of view and was clear and crisp through 10mm eyepieces, with no sign

Above: The BT81S-A is capable of providing views of a wide selection of Solar System and deep-sky objects

Left: The instrument employs a push-fit mechanism with a holding screw to keep 1.25" eyepieces secure

Right: Thanks to a magnesium fluoride coating on the lenses, chromatic aberration was kept to a minimum

> "The BT81S-A is more suited to wide-field deep-sky objects such as bright galaxies, star clusters and double stars"

of chromatic aberration – also known as colour-fringing – thanks to a magnesium fluoride coating on the lenses. Craters, lunar seas and the rugged surface in general were in superb high resolution.

Moving over to the second planet from the Sun, Venus, we picked up an obvious phase before heading over to Jupiter to see if the telescope binocular could pick out any detail on the gas giant. We weren't disappointed as we could just about make out Jupiter's belts and the four tiny points of light that were the Galilean moons Io, Europa, Ganymede and Callisto. The more we toured the May and June night skies, the more that we appreciated that the BT81S-A is more suited to wide-field deep-sky objects such as bright galaxies, star clusters and double stars, which were cleanly split into their components. Solar System targets turned out well, but given that they only appeared as very small discs, we enjoyed our deep-sky views much more. When it came to looking at brighter stars, we did detect a degree of internal reflections that led to ghosting.

Overall, we are very impressed with the BT81S-A. However, we would say that it's more geared towards astronomers who have been stargazing for a considerable amount of time. Beginners to astronomy may find they are better off buying a telescope that comes with all of the essentials, such as a tripod, starter eyepieces and finderscope, but if you're taken by the fact that you're able to view a good selection of night-sky objects with both eyes, then we can definitely recommend the BT81S-A.

WIN ASTRONOMY KIT

Courtesy of Hama UK and Meade Instruments Ltd, we've got two telescopes and a spotting scope worth over £1000 to give away

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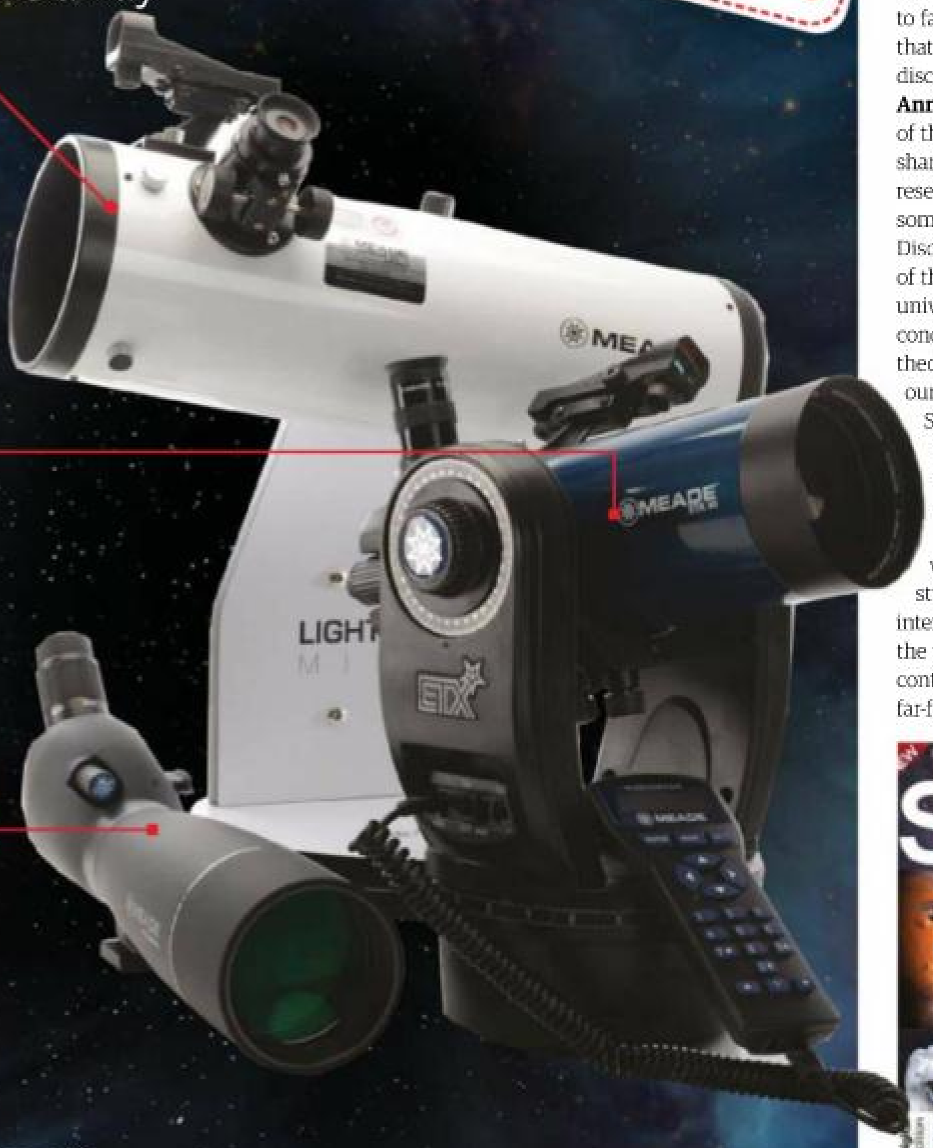

Meade LightBridge Mini 114

The ultimate grab-and-go telescope, it provides the same high-quality standards of the original truss-tube Dobsonian models but in a portable form. The Meade LightBridge Mini 114 offers magnificent views of planets, nebulae, star clusters and galaxies thanks to its excellent light-gathering ability.

Meade ETX90 Observer

Get stuck into astronomy with the ETX90 Observer. This automated and portable telescope provides exquisite views of a menagerie of night-sky objects – from the Solar System to galaxies and nebulae – thanks to its exquisite Maksutov-Cassegrain optical design with extraordinary contrast.

Meade Wilderness 20-60×80 spotting scope

Featuring high-index BaK-4 prisms as well as high-quality precision lenses finished with layers of anti-reflection coating for optimal performance, the Meade Wilderness is ideal for those who enjoy nothing more than dabbling in everything from bird-watching to observing the night sky.

To be in with a chance of winning, all you have to do is answer this question:

In which constellation can you find the Black Eye Galaxy (Messier 64)?

A: Leo

B: Coma Berenices

C: Virgo

Competition ends on 18 July 2019

Congratulations to John Gatehouse, the winner of the Omegon MightyMak 60 telescope and *An Astronomer's Tale* book

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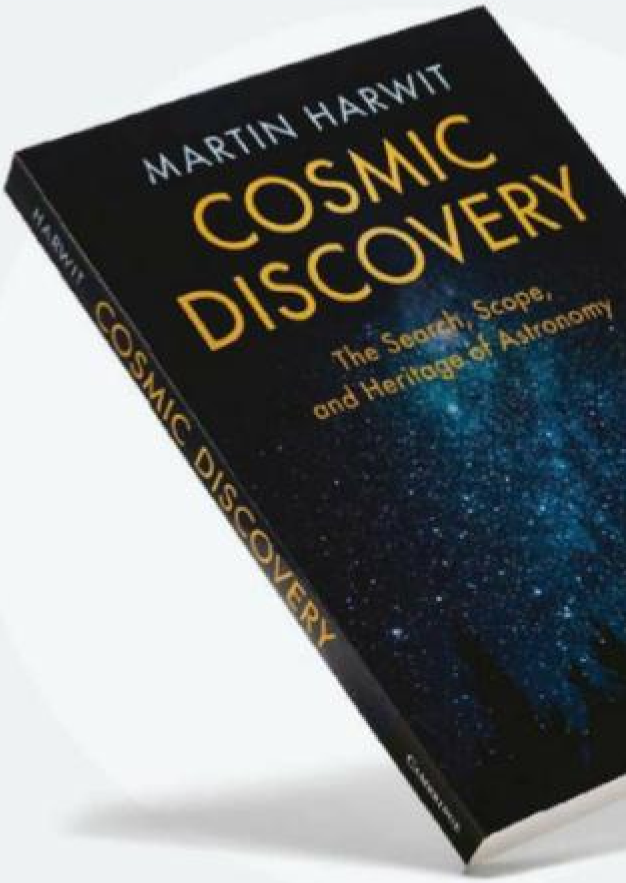


Book

Cosmic Discovery

Cost: £34.99 ($44.35)
From: Cambridge University Press

Martin Harwit's influential book, *Cosmic Discovery*, is rereleased after more than 35 years, with a new preface written by the author. The work chronicles the astronomical discoveries up to the late-20th century and draws conclusions that major discoveries have often been unexpected, unrelated to prevailing astronomical theories and made by outsiders from other fields. One trend alone seems to prevail: major discoveries follow major technological innovations in observational instruments. The author also examines discovery in terms of its political, financial and sociological contexts, including the role of industry and the military in enabling new technologies and methods of funding. The challenges encountered in astronomy in the 1980s are remarkably similar to those astronomers face today. Difficulties persist in controlling recurrent cost overruns on planned missions and in confronting mounting costs in developing observatories for detecting gravitational waves, high-energy cosmic rays and particles that might explain dark matter.

Mini telescope

Sky-Watcher Infinity-76P

Cost: £45 (approx. $57)
From: Royal Observatory Greenwich

Designed to entertain and inspire young minds, the Sky-Watcher Infinity 76P telescope is an ideal beginners telescope, especially for children. Featuring aspherical technology which is housed inside the telescope, this tech is usually reserved for larger and more expensive telescopes. The primary mirror is designed to bring in the light rays of a common focal plane, resulting in intricate and sharp images which are full of detail.

This grab-and-go instrument features an eyepiece with x30 magnification, a 76mm diameter parabolic primary mirror and a table-top cradle for stable viewing from the comfort of your own home.

The telescope is almost ready to go straight from the box for even the most impatient. Its intuitive manoeuvrability makes it incredibly user friendly to explore the universe to your hearts content.

Software

Google Sky

Cost: Free
From: Google

Many of us will have spent hours online on Google Maps or Google Earth, perusing satellite imagery of our planet or driving down roads all over Earth via Google's camera car. However, Google hasn't only been looking down - it's looked up too, and the result is Google Sky. Accessible via the Google Earth website and downloadable as an app with augmented-reality capabilities on Android phones, Google Sky lets you wander around the universe in the same manner as Google Earth allows you to explore our planet. It has different layers, including maps of the constellations; deep-space imagery from various observatories, including the Hubble Space Telescope and the Sloan Digital Sky Survey; podcasts that describe what is happening in the night sky right now; views of the sky across different wavelengths, such as in infrared light; user and science guides and the positions and orbits of the planets, asteroids and comets within our own Solar System.

> "Google Sky lets you wander around the universe"

Book

Apollo 11: The Inside Story

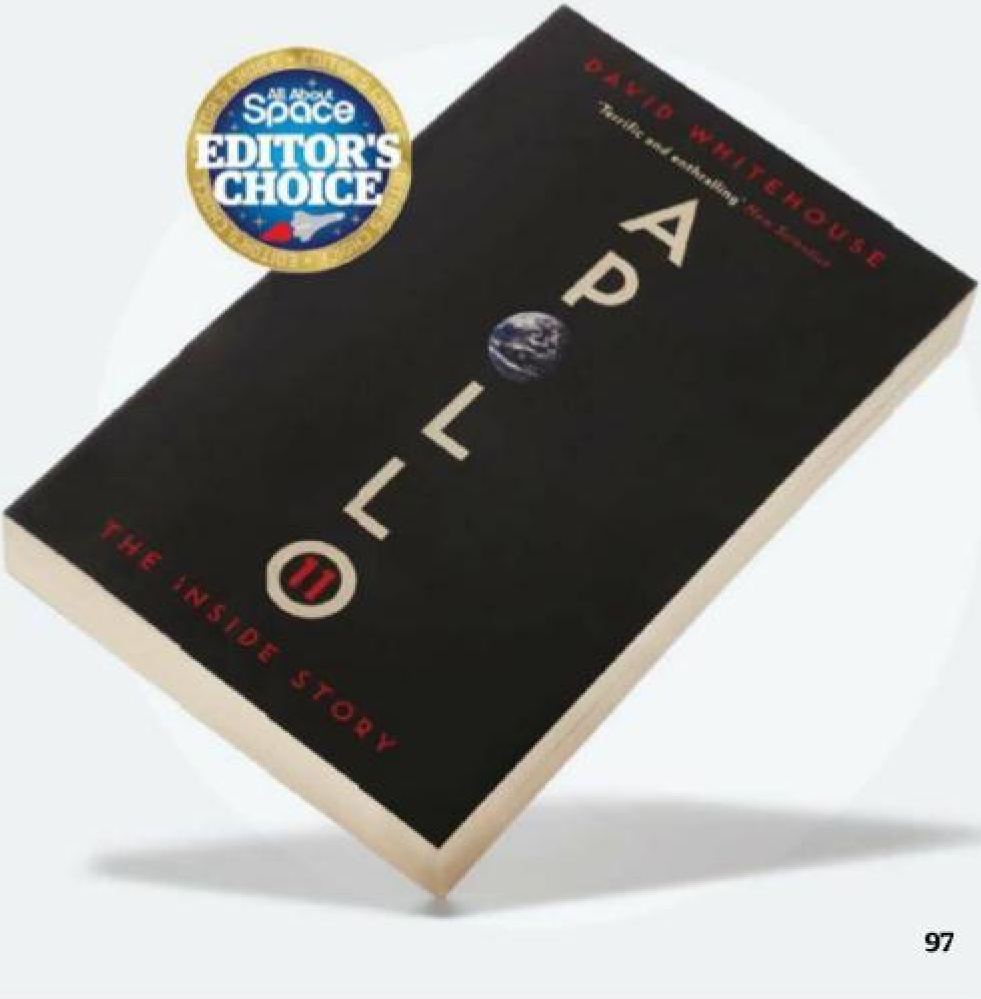
Cost: £15.79 (approx. $20)
From: Icon Books

50 years ago in July 1969, Apollo 11 became the first manned mission to land on the Moon, and Neil Armstrong the first man to step onto its surface. In the most authoritative book ever written about Apollo, David Whitehouse reveals the true drama behind the mission, telling the story in the words of those who took part based around exclusive interviews with the key players.

This enthralling book takes us from the early rocket pioneers to the shock America received from the Soviets' launch of the first satellite, Sputnik; from the race to put the first person into space, through President Kennedy's enthusiasm and later doubts to the astronauts' intense competition to leave the first footprint.

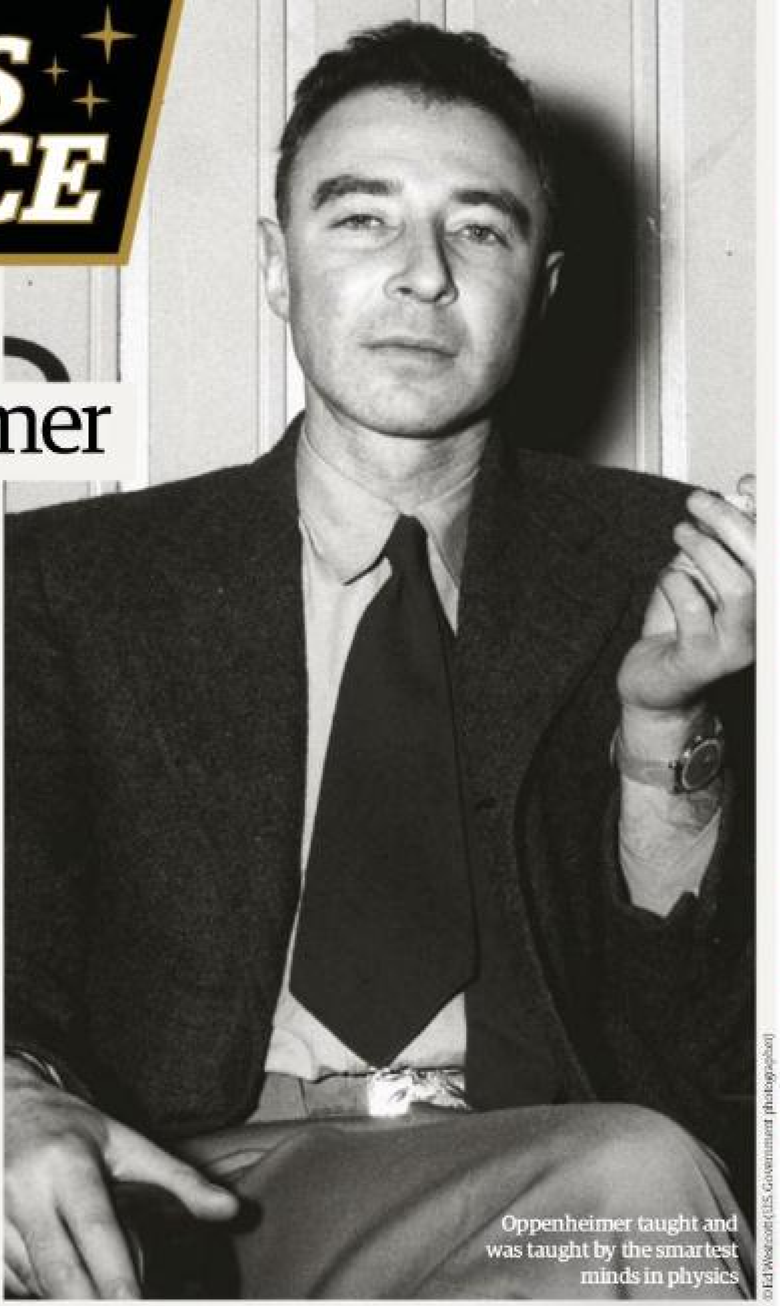
In celebration of the 50th Anniversary, here is the story as told by the crew of Apollo 11 and the many other astronauts who paved the way or followed themselves after the first man to walk on the Moon, Neil Armstrong, alongside Buzz Aldrin and Michael Collins. Astronauts, engineers, politicians, NASA officials, Soviet rivals - all tell their own story of a great moment of human achievement.

All About Space EDITOR'S CHOICE



J. Robert Oppenheimer

His World War II efforts may have made the headlines, but his work in physics should not be overlooked



Oppenheimer taught and was taught by the smartest minds in physics

© Ed Westcott (US Government photographer)

A man dubbed "the father of the atomic bomb" also played an important role in understanding quantum mechanics in the mid-20th century. He worked alongside many of the brightest minds in physics and even had the chance to manage them in accordance with the infamous Manhattan Project.

Born Julius Robert Oppenheimer on 22 April 1904 in New York City, United States, Oppenheimer took to science and maths from an early age and began travelling the world in the search of education. After he graduated summa cum laude – Latin for 'with highest honour' – from Harvard College in Cambridge, Massachusetts, he then took off to the United Kingdom to work in the Cavendish Laboratory at Cambridge University as a research assistant to J. J. Thomson – a Nobel Prize laureate in physics.

When he found the routine work in a laboratory to be fairly mundane, Oppenheimer took to the University of Göttingen in Germany to study quantum physics under the tutelage of Max Born and Neils Bohr, two iconic figures in quantum mechanics. In this time Oppenheimer helped devise the Born-Oppenheimer approximation, which in layman's terms means it is theoretically possible to separate an electron from atomic nuclei, and vice versa – a thought that is common knowledge now, but was a revelation at the time. Afterwards Oppenheimer jumped from one institute to another before settling down between two institutes in 1929. He divided his time between Caltech in Pasadena and the University of California, Berkeley, where he would tutor some of the rising stars in physics.

Oppenheimer also took an interest in astrophysics, and in particular the nature of neutron stars – extremely dense stars that are the leftover cores of much larger stars. In the late-1930s, Oppenheimer and his colleagues deduced the Tolman-Oppenheimer-Volkoff limit. This is an upper mass limit for stars made up of neutron-degenerate stars – in this case neutron stars. This limit even had a part to play in the recent gravitational waves detection between two neutron stars merging. This signal, known as GW170817, was able to suggest the limit was close to 2.17 solar masses.

When World War II began, Oppenheimer led a team of the brightest minds in creating the first atomic bomb in a study known as the Manhattan Project. Together they developed the bombs 'Little Boy' and 'Fat Man' that were dropped on Hiroshima and Nagasaki in Japan respectively. This effectively ended World War II as it forced Japan to surrender.

Although Oppenheimer's life and work afterwards were largely dominated by private and political issues, he was still able to release five scientific papers post-World War II. His legacy, upon reflection, has had a fundamental effect on quantum mechanics and science in general. He received the Enrico Fermi Award in 1963 before passing away due to throat cancer on 18 February 1967.

> "Oppenheimer also took an interest in astrophysics, and in particular the nature of neutron stars"

All About Space

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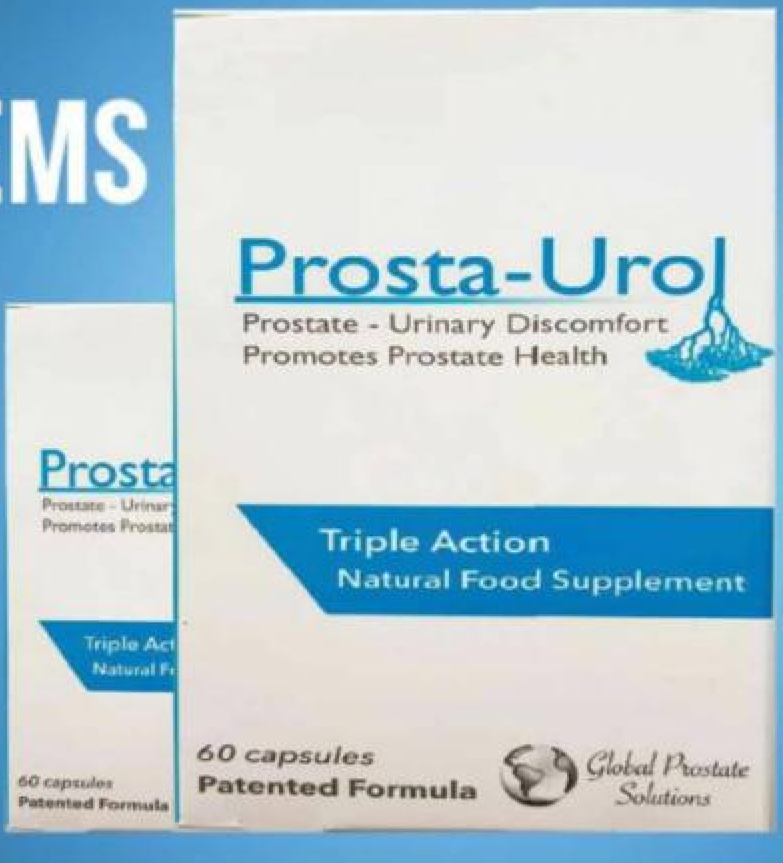

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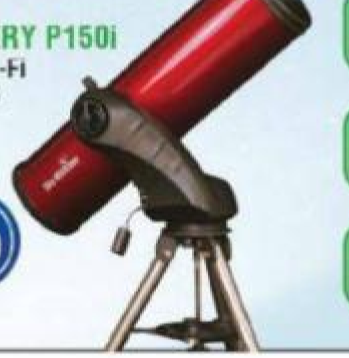

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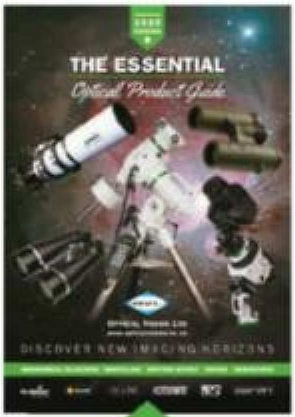

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